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Introduction

This course has been developed to cover Geosynthetics composite lining systems, the installation, deployment and welding and jointing of products within the containment and landfill construction industry.

The welding of geomembranes , installation, deployment and all associated activities is specialised work and it is imperative that all personnel working within the construction of containment developments have a good understanding of the make up of the materials they are working with, together with a good understanding of the effects on these materials by the various joining and associated construction processes. This course has been prepared in line with the CSWIP certification scheme for thermoplastic welders (CSWIP-PW-6-96).

Welding and Jointing

The welding and jointing of geosynthetic products is a specialised business that requires knowledge and experience in order to produce successful joints or welds. The equipment used today is very sophisticated and a good working knowledge of mechanical and electrical principles is necessary in order to understand and operate the machinery successfully. The general success or failure of a weld will be directly related to the operator's input regarding calibrating and setting up the parameters of the machine, in terms of the relationship between the three essential welding parameters i.e. temperature, pressure and speed. After the welding procedure has been carried out, it is important that the installation technician understands how to identify a good or bad weld both visually and by destructive and non-destructive testing methods. A well-trained technician should be able to examine a bad joint or poor weld and be able to identify why it is not of the required standard and how to rectify the situation to achieve a joint or weld to the required strength or specification. They should know which of the three welding parameters was not correctly set during the welding operation and should know how to re-calibrate the welding equipment in order to maintain consistent weld test results.

Equipment

Equipment for undertaking welding and jointing of geosynthetics should be specifically adapted for use on containment and landfill type applications. The environment in which this type of work is undertaken can be extremely variable depending upon site location and climatic conditions. The welding equipment used must be able to continually monitor and control the working temperature, ensuring that a constant weld temperature within the material melt-flow range is maintained.

Associated site activities

Undertaking site activities before and after geosynthetic installation has a direct implication on the integrity and performance of a lining system and must be undertaken by a person with the correct training and knowledge. Lining systems can be damaged from associated activities resulting in time consuming and costly repairs. In addition, reworking can cause project delays and ultimately an overdue client hand over. This can result in claims for liquidated damages and loss of confidence in the contractor's ability to undertake future lining developments/contracts.

Awareness of applicable standards

In February 1999 the Environment Agency produced an "Interim Guidance on the use of Geomembranes in Landfill Engineering". The document deals with both quality control and quality assurance for manufacturing and installation of geomembranes, looking at the materials themselves and the important factors to be considered in design.

The guidance relates to the use of geomembranes in landfill engineering and is based on the guidance outlined in the following Department of Environment publications, "Waste Management Paper No. 26B, Landfill Design, Construction and Operational Practice" and "Guidance for Good Practice for Landfill Engineering."

Page 95 of WMP 26B quotes two principle references used to provide more detailed guidance on all aspects of landfill lining systems to which designers are recommended to refer, these are: -

- Guidance on Good Practice for Landfill Engineering.

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- Quality assurance and Quality Control for Waste Containment facilities (United States Environmental Protection Agency – USEPA).

If the installation of a geomembrane is to be a success it is essential that quality products be used. There are currently no standards in the UK for the MQC of geomembranes, however a publication by the Geosythetic Research Institute (June 1997) provides a standard, which covers HDPE geomembranes. It should be recognised that this standard was originally developed for the market in the US and parts of it may not be fully applicable to other manufacturers of geomembranes.

Company accreditation

The Geosynthetics Installation Company Accreditation Scheme (CAS) was launched in 2015. The CAS scheme is designed to assess the competence of the installation company through independent auditing of their site files, site working practices, company records, policies and documents.

The Environment Agency has requested that from January 2020 any company installing geomembrane for the containment sector must hold a valid BGA/TWI CAS certificate (or equivalent). The requirement will be included in the initial CQA plan. Furthermore, a verified CAS certifcate will be shown in the project validation report.

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1 Health and Safety

Every employer must ensure, so far as is reasonably practicable, the health and safety of his employees and others (Health and Safety at Work etc Act 1974, Section 2 and 3). This extends to the provision and maintenance of equipment, plant and systems, machinery guarding and layout.

1.1 Electrical safety

1.1.1 What causes electrical shock?

The simple answer is ‘electricity’, but it will be helpful to have a rather more precise idea. Electric currents in the region of 1mA (1 milli-amp = 1 thousandth of an amp) passing through the human body cause a distinct feeling of ‘shock’: the muscles contract. Currents up to around 40mA can cause contraction of the muscles of the heart and lungs, stopping heart action and breathing. Prompt first aid action to remove the source of electric shock and to get the heart and breathing going again, using chest compression followed by mouth-to-mouth resuscitation, can save life. Higher currents still can cause internal burning of the muscles and death.

The muscular contraction can make comparatively low-current shocks worse in two ways:

- The victim may be unable to let go of the object which is giving him the shock, particularly where he has held it in his hand rather than just touched it.
- Sudden limb movement may cause injury (if they fall off a ladder, for example).

1.1.2 Avoiding electric shock

1.2 Use of 240 volts and 110 volt equipment

Electrical power supplies are made up of three components: the voltage (in volts), the current (in amps) and the power (in watts). The power rating of any piece of equipment can be calculated by multiplying the current by the voltage. Therefore, if a piece of equipment is rated at 1 kilowatt (1,000 watts), then it will draw 4.5 amps at 220 volts. If, however, it were plugged into a 110-volt supply, then it would draw nine amps. In almost all machines, connection to the wrong power supply would cause serious damage, and may be extremely dangerous.

The power supplies may be either alternating (AC) or direct (DC). Alternating current supplies continuously vary between zero and maximum 50 times a second, while direct supplies stay at maximum continuously. Alternating current can be transformed upwards to 220 volts. Direct supplies can be reduced using resistors, but cannot be increased above their normal maximum.

Irrespective of whether the supply is AC or DC, the current flows along the LIVE cable, and returns through the NEUTRAL cable. European standards require that the live cable is coloured brown, and the neutral is coloured blue. In addition, an EARTH connection, coloured yellow/green, may be required. This simply provides a possible return path for the electricity through the earth, but that will only work if the electricity supply point (generator, etc.) is also connected to earth. Generators standing on a HDPE liner cannot have any earth connection, since the liner provides an electrical barrier. Modern hand tools (angle grinders, etc.) are so heavily insulated that they do not require an earth connection. On American-built equipment, live is black, white is neutral and earth is green.

Plant, tools, and equipment used by geomembrane installers are generally rated at 220v. This contradicts most construction site rules; however it is acceptable to use this equipment (within HSE guidelines) as long as sufficient risk assessments and additional control measures are implemented.

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There were a number of fatalities, when using power tools, during the 1980's, when construction industry guidelines were being developed. Upon further investigation, the actual cause of the fatality was from the user being thrown from height, (ie working on scaffold) or falling onto items around the work area. To reduce the number of fatalities it was decided to reduce the voltage of power equipment to 110 volts. With the development of sophisticated battery technology the voltage required for power tools, such as saws and drills, has dropped further to 18 or 24 volts. Unfortunately welding equipment needs high wattage (if the voltage is reduced) to maintain the temperatures required for welding

Wattage = volts multiplied by amps.

4.5kW welding machine =4500 watts

4500 divide by 110 volts = 40.9 amps

4500 divide by 220 volts = 20.9 amps

To achieve and maintain heat on welding equipment with reduced voltage then a large increase in amps is needed. Increased amps will increase the likelihood hood of death from electric shock. High voltage will cause you to take a shock, high current will kill you.

A secondary issue with the increase of amperage is the length of cables from the power source (generator) and therefore potential power drop off. On large lining sites, where long welding seams are required then long cables are needed to cover the work area. When higher amperage is run though the cable, resistance within the cable, joints and sockets becomes greater, and heat is generated. This can also create a power drop along the length of the cable and could interfere with the settings of the welding machine. To control this issue larger cables are required.

Sundry equipment (sanders, hot air welders tensometers etc.) are readily available in 110 volts but to keep consistency all equipment on site should use the same voltage, as to prevent the risk of cross-contamination of power supplies.

Some wedge welders are supplied at 220 volts, but have heaters rated at 110 volts. This voltage reduction is achieved by connecting the two cartridge heaters in SERIES; that is, the currents pass through the first, and then through the second, rather than through both at the same time. Each cartridge uses 110 volts, and 110 volts + 110 volts = 220 volts. Once again, incorrect connection of the cartridges, or connection to the wrong supply voltage will cause serious damage, and may be dangerous.

All electrical equipment is clearly marked to show the supply voltage, the power in watts or kilowatts, and the current drawn.

All electrical equipment is clearly marked to show the supply voltage, this is shown by having different coloured plug and sockets made up of:

- Yellow 110 volt single phase
- Blue 240 volt single phase
- Red 415 volt three phase.

Wedge and extrusion welders, and most hand tools, used in the lining business are rated at 220 volts AC. This is to minimise the voltage drop in cables, and to limit the size of the machines. A 110-volt machine needs twice the current to provide the same power output, and to withstand that, it must be larger and more cumbersome.

Site equipment that requires power should always be supplied with a Residual Current Device (RCD units). RCD units work by continuously monitoring the amount of electric

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current flowing in the live and neutral cables. The theory is that the same amount of current in amps should be passing through each cable, when power is being demanded. If a difference greater than 30 thousandths of an amp arises, then the RCD will trip out.

1.3 Fume

1.3.1 What is fume?

Most welding gives off fumes, which pollute the surrounding air. These can be divided into airborne fine particles and gases.

The size of the particles produced during welding ranges from around 0.01□m to 100□m. The respirable fraction of particles (especially those less than around 1□m) are potentially the more harmful as they can penetrate to the innermost parts of the lungs.

Gases are the individual molecules of a chemical compound, which do not aggregate into a liquid or solid.

1.3.2 Measurement and OELs (Occupational Exposure Limits)

There is no reliable link between the visibility, the nuisance and the harmfulness of fume, except where it is of known composition and size distribution, which is likely to be the case only where a closely defined process is involved.

Gases are generally invisible. The amount of fume released by welding may be estimated by assuming that all the potentially hazardous compounds are formed but this usually turns out to be a gross over-estimate. The only way of obtaining a reliable answer is to measure the concentrations under known conditions for a range of welding processes, consumables and applications and to estimate the repeatability of measurements to facilitate predictions.

Measurements are usually made in the breathing zone of the welder. Particulate fume is measured by drawing a known volume of air through a fine filter paper: by weighing the paper before and after, the total amount of particulate fume is calculated in milligrams per cubic metre (mg/m^3).

Gases are measured with a similar sampling technique, using a directly indicating analyser giving almost instantaneous readings of a particular gas, or storing a sample for subsequent conventional analysis. Results are expressed as the concentration in parts per million (ppm).

1.3.3 Check list for welding fumes

- Use as much ventilation as possible.
- Use extractor systems and/or respirators when welding in confined spaces or when excess fume is generated.
- Remove surface coatings from areas to be welded.
- When welding tanks and pipes used to carry inflammable liquids, ensure they have been cleaned to workshop safety standards and have a certificate to support it.
- Remove de-greasing agents from the sheets to be welded.

1.4 Care and use of electrical/hand tools and lifting tackle commonly used by the welder

Electrical tools

All electrical equipment on site must have test information available. Equipment should be individually tagged and clearly show the retest date. Welding technicians should check the test validity date prior to use.

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1 Always ensure that the tool is in good condition, and do not use it if there is any visible damage.
2 Check the power cable. Make sure that the insulation is undamaged and that the cable is securely connected to the tool and to the plug.
3 Do not allow electrical tools to become wet.
4 Do not use electrical tools while standing in water.
5 Do not use hand sanders for cutting, without the wheel guard in place.
6 Do not use damaged sanding disks.
7 Always wear goggles and ear defenders when using angle grinders.
8 Remove inflammable materials from the area before using angle grinders to grind or cut metal.
9 Wear industrial gloves when using sanders or hot air tools.
10 Ensure that the hot air gun welding nozzles are securely fixed to the barrels of the tools.
11 Do not touch hot air gun barrels when the tools are in use.
12 Always turn down the heat control on any hot air tool that is not being used.
13 Take care not to put a hot air tool down in such a way that it might ignite inflammable materials.
14 Ensure that all electrical hand tools are fitted with industrial electrical plugs of the correct rating, and that the plugs are in perfect condition.

Hand tools

1 Make sure that all hand tools are in perfect condition.
2 Do not use spanners with damaged jaws.
3 Do not use blunt hacksaw blades. Replace any that are blunted.
4 Discard hex keys that are worn.
5 Do not use screwdrivers as chisels, and do not sharpen them to a point.
6 Ensure that hammer heads are secure.
7 Do not use vice grips on nuts and screws—use only properly fitting spanners and hex keys.
8 Do not use files without secure handles.
9 When using craft knives or hook knives, cut away from yourself wherever possible. Make sure that no one nearby could be injured if the knife slips. Use only sharp blades. Wear industrial gloves when cutting. Only use hook blades for cutting liner, and only Don Carlos or similar knives for cutting welds.

Fusion welding machines

1 The wedges of fusion welders operate at around 360 degrees, and can cause severe burns. Keep hands well away from them, and be particularly careful not to touch them when introducing a machine into a seam.
2 The drive motors of fusion welders are very powerful, and the drive wheels can cause severe injury if fingers become trapped between them. Keep hands well away from them when the machine is running.
3 Never try to clean the drive wheels of a fusion welder with the drive running.
4 Ensure that all power cables are in good condition, with sound insulation. Ensure that the cables are securely connected to the machine and to the plug.
5 Check that the power supply plug is in good condition, that it is clean and dry, and that its seals are intact.
6 Ensure that the flexible cables to the wedge are undamaged, and that their insulation is sound.
7 Keep the electrical control boxes of machine dry and clean. Do not allow machines to stand outside in the rain.

Extrusion welding machines

1 The barrels of extrusion welding machines become very hot. Always ensure that their heat protective blankets are in good condition, and keep hands away from the barrels and their tips.
2 Take care not to touch the preheat tubes when the machines are operating.

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3 Do not lay machines down on the barrel thermocouples on hard surfaces. Make sure that the fitted stands are in good condition, and always put the machine down upon them.
4 All extrusion welders are inclined to overheat when first turned on, and this can cause them to spit molten extrudate. Always allow the temperature to stabilise before using the machine, and do not pull hardened extrudate from tips with bare hands.
5 After completing a weld with an extrusion welder, always clear the tip with a short length of welding rod.
6 Do not use machines with loose or poorly fitting teflon shoes.
7 Ensure that all power cables are in good condition, with sound insulation. Ensure that the cables are securely connected to the machine and to the plug.
8 Ensure that the flexible cables from the control box to the barrel and the preheat triac are undamaged, and that their insulation is sound.
9 Keep the electrical control boxes of machine dry and clean. Do not allow machines to stand outside in the rain

Lifting equipment

1 Carefully inspect all lifting equipment before use, and ensure that you have a copy of its test certificate. Check particularly for excessive rust and any signs of weakening or damage.
2 Make sure that the load you are about to lift is within the capacity of the equipment, as stamped upon the hooks, shackles, or joining rings.
3 Do not use chain slings where the angles of the legs are less than 45 degrees to the horizontal. In such cases, while the load may be within the capacity of the sling, the extra load caused by a shallow angle could still break it.
4 Before using hooks, make sure that the safety catch is secure and working properly.
5 Make sure that all shackles are of the correct load rating for the job, that they are undamaged, and that their pins are securely tightened.
6 Be particularly careful with wire ropes. Check for any broken strands or evidence of rusting, and do not attempt to wipe them with bare hands—an unseen strand could easily penetrate the skin and cause injury.
7 Do not use wire ropes at all if the job can be done in any other way.
8 Always use guide ropes when slinging heavy or cumbersome loads.
9 Never walk under a slung load.
10 Do not stand in front of slung rolls of liner or textile when deploying on slopes.
11 When using spreader beams, ensure that all securing pins are of the correct type, and that they are securely in place before starting to lift. Check that the beam is correctly loaded and that it is in good condition. Ensure that the cones are fully engaged in the roll core.
12 When using GCL beams, ensure that the beam is in good condition, and that its chains, shackles, and bar hooks are undamaged. Ensure that the bar hooks are securely home in the roll tube before starting to lift.
13 Always be aware of other people's movements, and ensure that any that are not directly involved in the lift keep well clear.

Working on landfill sites

1 When working on landfill sites, carry a company-issued Weill's Disease card at all times. Make sure that you are familiar with the message the card bears.
2 Always wear proper industrial protective clothing and boots with steel soles and toe caps.
3 Be aware of the dangers of hypodermic needles that may be hidden in the waste.
4 Look out for broken glass and sharp metal.
5 Be aware of the need for personal hygiene. Always wash hands before touching food, smoking, or toilet.
6 Enter all treatable accidents in the accident report book.

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Working in workshops

1 All machine tools (lathes, drills, bandsaws etc.) are extremely dangerous, and can cause serious injury. Do not touch them unless you have been fully trained to do so.
2 Do not use bench grinders for grinding large pieces of metal. They are for tool grinding only.
3 Do not leave tools and equipment lying about on the workshop floor where someone may trip over them.
4 Always be aware of other activities taking place around you. Do not stumble into danger by inattention.
5 Do not touch electric arc or gas welding and cutting equipment unless you have been fully trained to use it. Be aware of the dangers of very hot metal where welding or cutting is taking place.
6 Do not leave power cables lying across the floor unnecessarily.
7 When forklift trucks are operating, keep well clear. Do not attempt to drive them unless you are fully certificated to do so.
8 Be aware of where the workshop first aid kit is kept, and who the qualified first-aider is.
9 Do not leave barriers open on upper floor landing areas.
10 Do not allow an accumulation of combustible materials to develop.
11 Clean up all liquid spills immediately, before someone slips on them.
12 Workshops are confined spaces. Always be aware of the presence of others when using tools that could cause injury to them.
13 Use the lifting equipment available, or call for assistance. Do not attempt to lift excessive loads.
14 Do not take workshop extension leads (blue cables) out on site—they are unsuitable for site work.
15 Some chemicals commonly used in workshops are highly inflammable, potentially toxic, and most are skin irritants. Do not touch any chemical with which you are unfamiliar.
16 Keep the workshop clean and tidy at all times. Tidiness avoids accidents.
17 When working upon dirty or oily equipment, always use barrier cream, and wash hands regularly.
18 Treat all cuts, burns, and minor injuries immediately. Do not risk infection by leaving them untreated.

1.5 Heat burns and fire

Burns and fire

1 Always wear proper protective clothing, gloves, and goggles when undertaking any work involving hot tools or materials.
2 Know the basic first aid treatment for burns.
3 Know the location of the site first aid kit, and know who in the crew the qualified first-aider is.
4 Enter all treatable burns in the accident book.
5 Only treat burns with the proper medication supplied in the first aid kit.
6 Do not allow inflammable materials and scrap to build up in the working area.
7 Know the colour code for fire extinguishers, and know which type is suitable for the type of work in which you are involved. Make sure that you know how to operate all fire appliances, and where they are located.
8 Hand held fire appliances are intended for containment, not for fighting major fires. Always call emergency services before a fire becomes out of control, and do not take unnecessary risks in tackling it.
9 Do not use water extinguishers or hoses on electrical equipment fires, or on fires near electrical equipment.

1.6 Cutting Equipment

Various types of cutting equipment are used in the lining industry and most lining installation site accidents (resulting in injury) occur whilst undertaking this operation.

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A hook type cutting blade is generally used when cutting thicker membranes, as the shape of the blade gives the user more control when cutting the liner. Knives that allow the blade to be clamped during cutting will also give the user better control.

A straight bladed knife is used for cutting thinner geomembranes as hook blades tend to drag and pucker the liner during cutting. Heavy duty scissors can be used when detailed shaping of the lighter type membranes is required.

2 Materials Technology

2.1 Molecules and polymer chains

A plastic or polymer is a material made up of small molecular units, or monomers, formed into much longer molecular chains or networks. A single ethylene molecule, the basis of the common thermoplastic polyethylene (PE), is shown in Figure 2.1. It comprises of two carbon atoms and four hydrogen atoms.

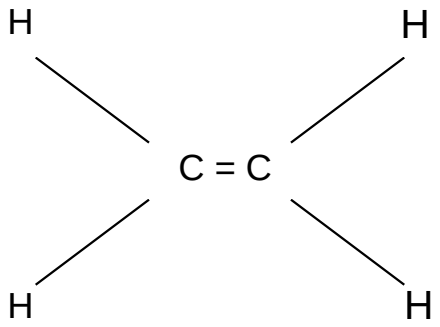


Figure 2.1 single ethylene molecule.

The double line between the carbon atoms indicates that there are two links or bonds between the atoms.

Figure 2.2 illustrates the formation of the molecular chain when the individual molecules are linked together to form the polymer (poly - meaning; many).

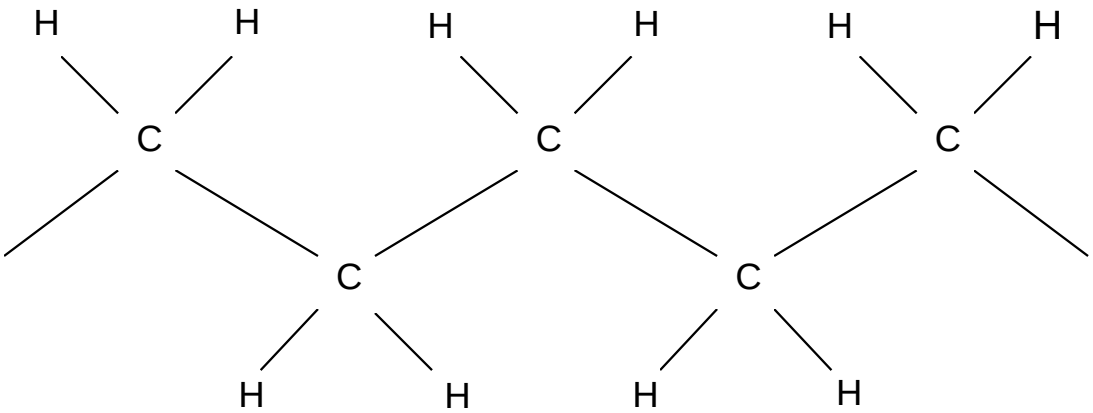


Figure 2.2 Basic chain construction of the polymer polyethylene.

During the process of manufacturing the polymer, one of the double links is broken and attached to the adjacent molecule.

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Figure 2.3 illustrates the polymer chain for another common plastic material – polyvinyl chloride (PVC). This basic molecule comprises two carbon atoms, three hydrogen atoms and one chlorine atom.

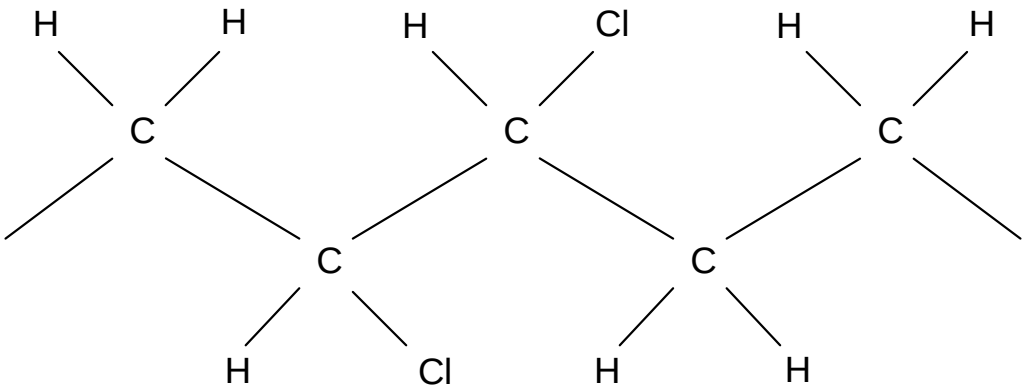


Figure 2.3 Basic chain construction of the polymer PVC.

The length of the chain, or molecular weight, dictates the form and properties of the final material. For example, candle wax is based upon the same molecule as polyethylene except the chain length is considerably shorter, around 40 monomers per chain length, as opposed to many thousands in polyethylene. Hence both materials have a similar feel when handled and smell when burned. As the chain length increases other properties change, for example, the toughness of the material increases, hence polyethylene is very much tougher than candle wax. Within any plastic, all the polymer chains will not be the same length. Therefore, when describing molecular weight, the average is usually quoted.

2.2 Plastic materials classification

There are two types of plastic material; thermoplastic and thermoset. Within the plastic material, there are many thousands of polymer chains closely interwoven to form the material structure.

In a thermoset plastic material there are a number of discrete links between adjacent polymer chains. This is illustrated in Figure 2.4.

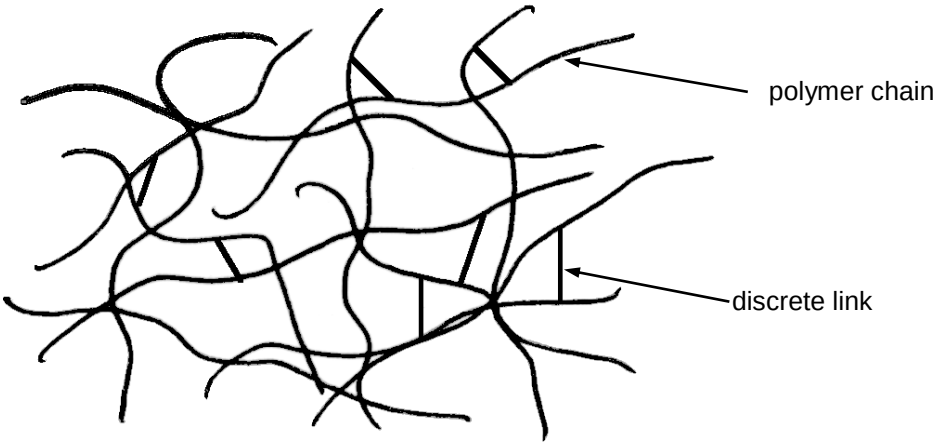


Figure 2.4 Structure of a thermoset material.

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The links are formed by chemical reaction and generally cannot be reversed by either chemical or heating reaction. These materials are, therefore, not weldable. An example of a common thermoset material is a two part epoxy resin, where the chemical reaction occurs when the two constituent parts are mixed. The final shape of the resin cannot be changed once the material has set or cured.

In a thermoplastic material the polymer chains are not linked and the polymer chains are free to move when heat is applied to the thermoplastic. When heat is applied, the thermoplastic material can be moulded and formed into a new shape, as in injection moulding. These materials are also, therefore, weldable by a range of techniques involving the application of heat.

Thermoplastic materials can be categorised into two further groups; amorphous and semi-crystalline. In an amorphous thermoplastic the polymer chains are randomly orientated within the thermoplastic material structure. This is shown in Figure 2.5.

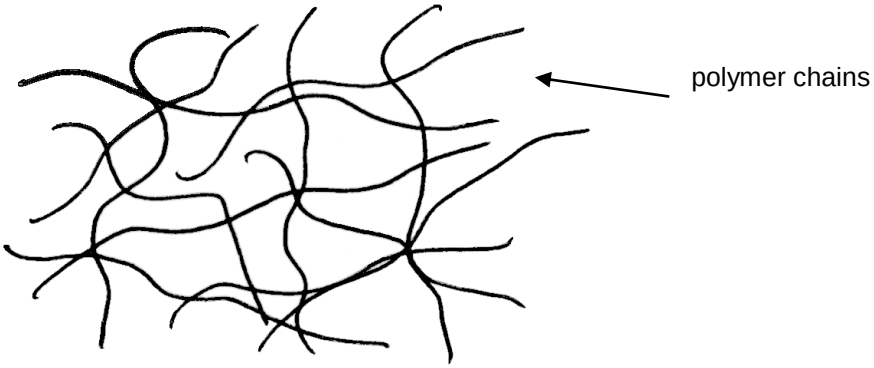


Figure 2.5 Amorphous thermoplastic material structure.

Amorphous thermoplastics can be clear, have uniform (isotropic) properties in all directions and have a softening temperature range rather than a melting point. PVC, a common thermoplastic used in industrial fabrication, is a typical amorphous thermoplastic.

In a semicrystalline thermoplastic, the polymer chains are organised in a more ordered structure. This is shown in Figure 2.6.

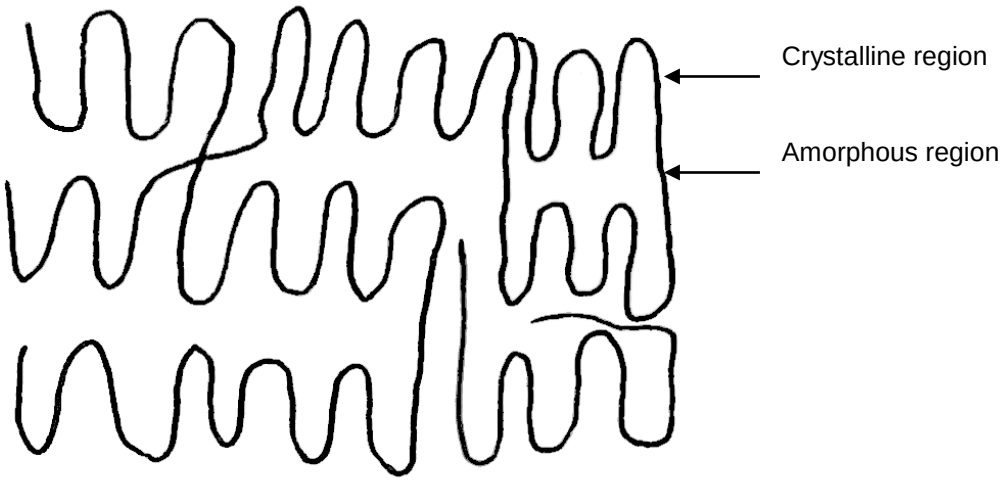


Figure 2.6 Semicrystalline thermoplastic material structure.

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Note that these materials are not wholly crystalline, as in salts or metals, but contain amorphous regions in between the crystalline structure. When a semicrystalline thermoplastic material is heated, the crystalline structure relaxes into an amorphous type structure during melting. Semicrystalline thermoplastics are generally characterised by their opacity, non uniform (anisotropic) properties, and distinct or narrow melt temperature range. Polyethylene and polypropylene are two common semicrystalline thermoplastics used in industrial fabrications.

Figure 2.7 summarises Section 2.2, the material classification in relation to welding of plastics.

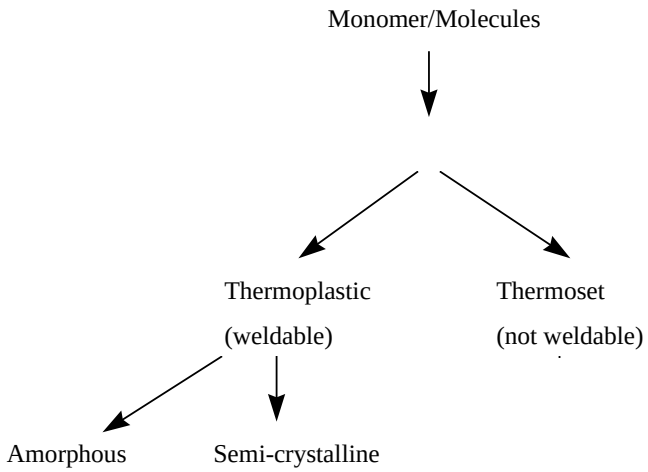


Figure 2.7 Summary of weldable/non weldable plastic classification.

2.3 Copolymers

Another important aspect of the thermoplastic structure is the chemical construction of the polymer chain. A polymer chain can consist of a string of identical monomer units as in polyethylene. These materials are known as homopolymers. Figure 2.8 shows a typical arrangement of a homopolymer. Each box in the chain represents a single monomer unit.

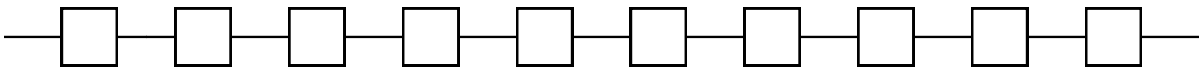


Figure 2.8 Homopolymer chain construction.

In some thermoplastics materials, the polymer chain can be constructed from more than one monomer, as is the case in certain polypropylenes. In these materials, the monomer units are arranged randomly or in blocks along the polymer chain. The different types are illustrated in Figure 2.9.

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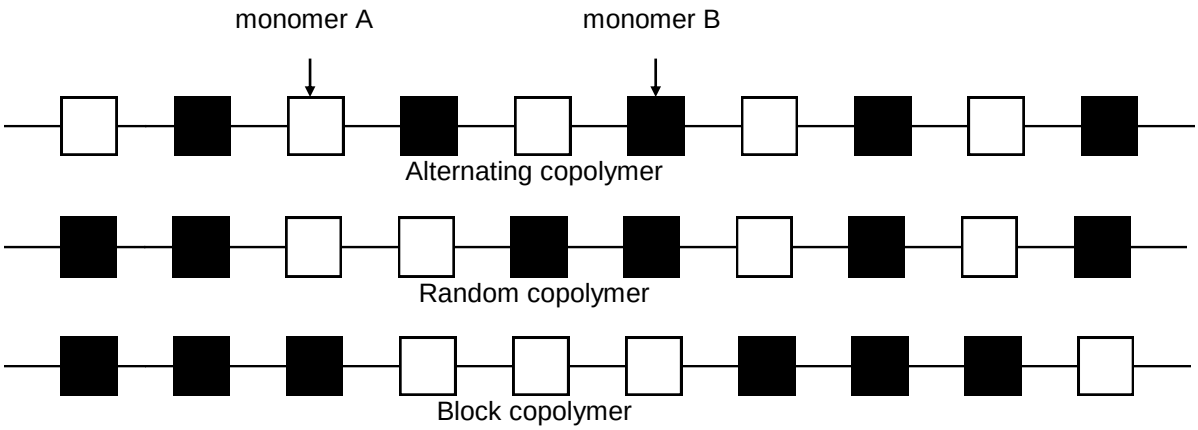


Figure.2.9 Copolymer chain constructions.

Each polymer chain construction will give rise to different material properties, for example, random copolymer polypropylene (PP-R) is more ductile and easier to bend than homopolymer polypropylene (PP-H). It will also have different characteristics when welding.

2.4 Glass transition temperature - TG

A very important property of any thermoplastic is the glass transition temperature (Tg). Below Tg the polymer chains remain rigid and cannot flex. Above the Tg, the polymer chains are free to move and the material appears to be rather more like a rubber than a solid plastic. When the material cools to below the Tg, the material becomes rigid once again. The Tg of the material is not always constant and can be affected by environmental effects such as exposure to ultraviolet light. It will also depend upon the material's molecular weight. Increasing chain length will generally increase the Tg of the material.

Table 2.1 lists the common thermoplastics used in industrial fabrication along with their Tg and melting point.

Table 2.1 Approximate glass transition temperatures and melting points of commonly used thermoplastics

Materials	Type	APPROX Tg(1),°C	MELTING POINT (1),°C
Polyethylene (HD)	SC	-125	125 to 135
Polyethylene (LD)	SC	-130	105 to 115
Polypropylene	SC	-20 to 0	145 to 170
PVC	A	80 to 90	

(1) will vary with grade, SC = semicrystalline, A = amorphous

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3 Thermoplastic Geomembranes

3.1 Introduction

The general term for geomembranes is “Flexible Membrane Liners” (FML). Polymeric resins and processing methods have evolved over time providing many products that will serve their intended design function, but have been inaccurately named, titled and described. As more products become available it is important to understand the various polymeric geomembrane materials. Some geomembrane sheets are compounded versions of relatively ridged thermoplastic polymers, such as PVC. Other geomembranes are compounded versions of elastomers, such as chlorosulfonated polyethylene (CSPE). Each is formulated with specific expectations in mind ranging from long term flexibility, to long term weatherability, to cost.

The main geomembranes that we are concerned with for the purposes of this document are HDPE, PP and PVC.

3.2 Key properties

3.2.1 Permeability

Geomembranes are impermeable liquid or vapour barriers, usually made from thin continuous polymeric sheets that are very flexible. Geomembranes are not absolutely impermeable, but are relatively impermeable when compared to geotextiles or soils. Typical values of permeability as measured by water vapour transmission test are in the range 0.5 x 10-10 to 0.5 x 10-13 m/s. While the primary function of geomembranes is as a barrier to liquids or vapours, the uses for geomembranes are wide and varied and the market is continually growing.

3.2.2 Density

The density or specific gravity of a geomembrane is dependent on the base material from which it is made. There are distinct differences however even in the same generic polymer; for example, PE comes in very low density, low density, linear low density, medium density, and high density varieties. The ASTM classification for HDPE resin requires a density greater than or equal to 941kg/m^3. However, all commercially available HDPE geomembranes use resin with a density between 934 and 938kg/m^3, which is actually in the medium density range. Only by adding carbon black and additives to the formulation is the gross density raised to 941kg/m^3 or slightly higher. Therefore, what is called HDPE by the geomembrane industry is actually MDPE resin to the polymer producer.

3.2.3 Melt flow index

Another important property for geomembranes is the melt flow index (MFI). This is routinely measured by geomembrane manufacturers as a method of controlling polymer uniformity. It relates to the flow ability of the polymer in its molten state. It is used for both the incoming resin and the final geomembrane sheet.

The MFI of a polymer is determined by measuring the rate of extrusion of the molten material through a die of specified length and diameter under prescribed conditions of temperature, load and piston position in the barrel. The MFI of a geomembrane will have a direct impact on the parameter set to weld it. For extrusion and wedge welding it is important both molten polymer components flow at the same rate (when welding temperatures are set). To ensure optimum welding, the MFI of the two components to be welded should be as close as possible. Significant differences in MFI could result in poor welds being produced. Therefore, it is advisable that welding rod and sheet is sourced from not only the same manufacturer, but also from the same production facility.

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3.3 Manufacture of geomembrane

The manufacturing of geomembranes begins with the production of the raw materials, which include the polymer resin itself; various additives, such as antioxidants, plasticizers, fillers, and carbon black; and lubricants (as a processing aid). These raw materials are then processed into geomembrane sheets of various widths and thicknesses (see Figure 3.1).

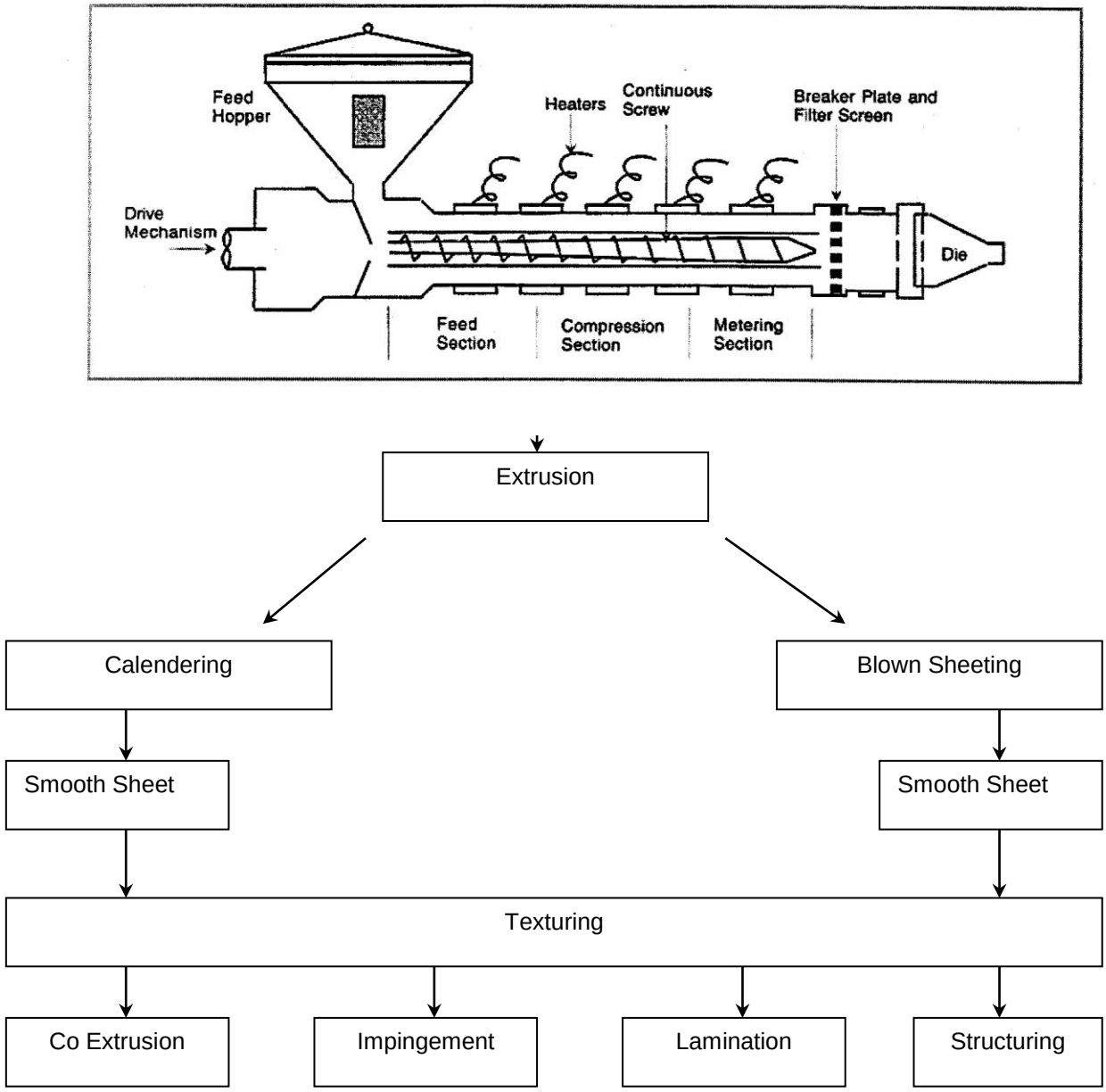


Figure 3.1 Various methods used to manufacture geomembranes.

All polyethylene geomembranes and some flexible polypropylenes (FPP) are manufactured by the extrusion method. In this method the polymer resin, carbon black (usually in pellet form premixed with it as carrier resin), and an additive package (antioxidant and lubricant) are pneumatically loaded into the feed hopper of an extruder (see Figure 3.2). The extruder contains a rotating continuous flight screw. The formulation passes successively through a feed section, compression section, and metering section where it finally emerges as a filtered, mixed, and molten material into a die. Two variations of extrusion processing are

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then used to make geomembranes. One process uses a flat die (called cast sheeting), which forces the polymer formulation between two horizontal die lips, in a coathanger-line manner, resulting in a sheet of closely controlled thickness from 0.5 to 3mm. The sheet widths vary from 1.8 to 9.3m.

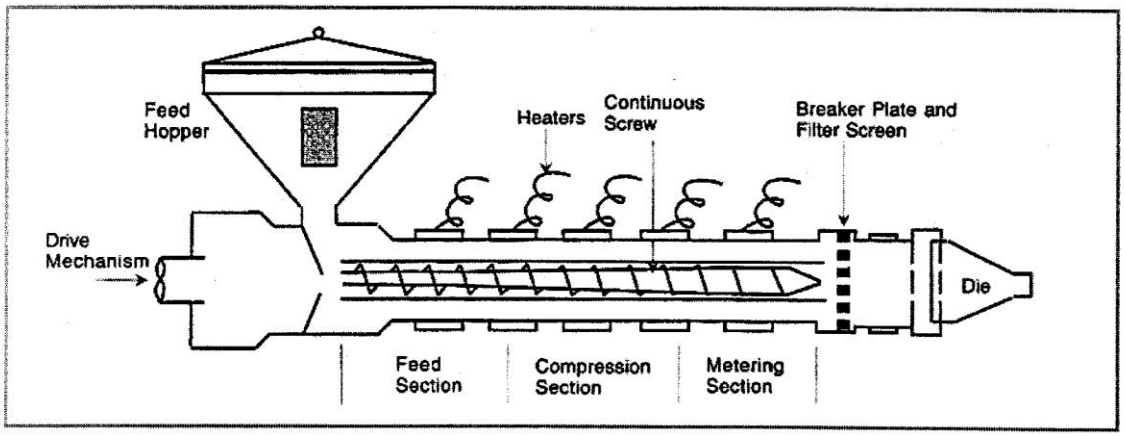


Figure 3.2 Cross-section diagram of a horizontal single-screw extruder for polymer processing.

The second process uses a circular die (called blown film), which forces the polymer formulation between two concentric die lips oriented vertically (see Figure 3.3). The polymer formulation exits the die and is supported by a large circular internal mandrel as it eventually extends upward into a cylinder (see Figure 3.4). At the top of the system, two counter rotating rollers draw the cylinder upward and maintain stability. After passing over the rollers, the sheet is longitudinally cut, unfolded to its full width, and rolled onto a take-up core. Geomembranes produced by both types of extrusions are transported to the job site and installed in the field where they are field-seamed together into a completed line system.

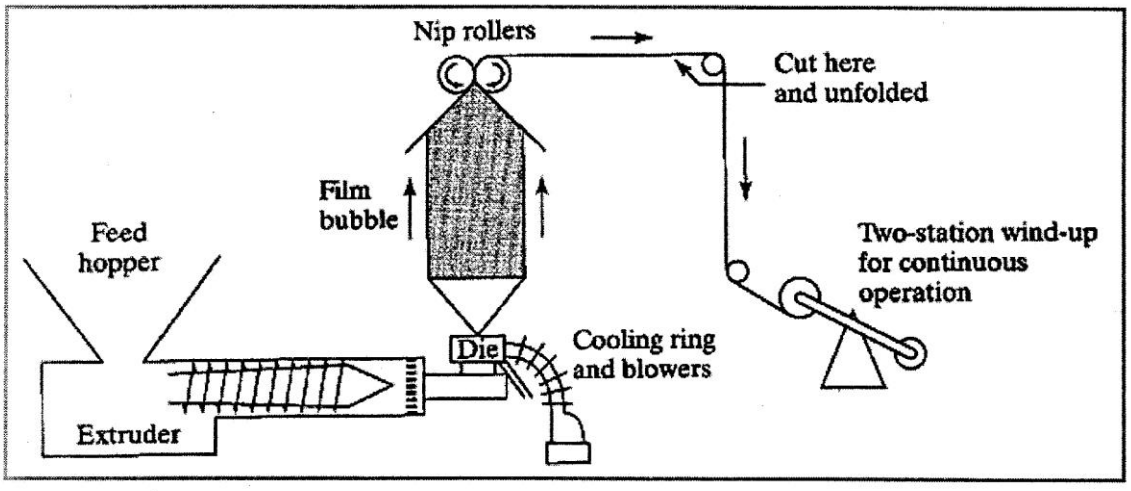


Figure 3.3 Diagram of processing of geomembranes by blown sheet extrusion.

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Figure 3.4 Processing of geomembranes by blown sheet extrusion.

A photograph of the flat sheet extrusion geomembrane processing technique is shown in Figure 3.5.

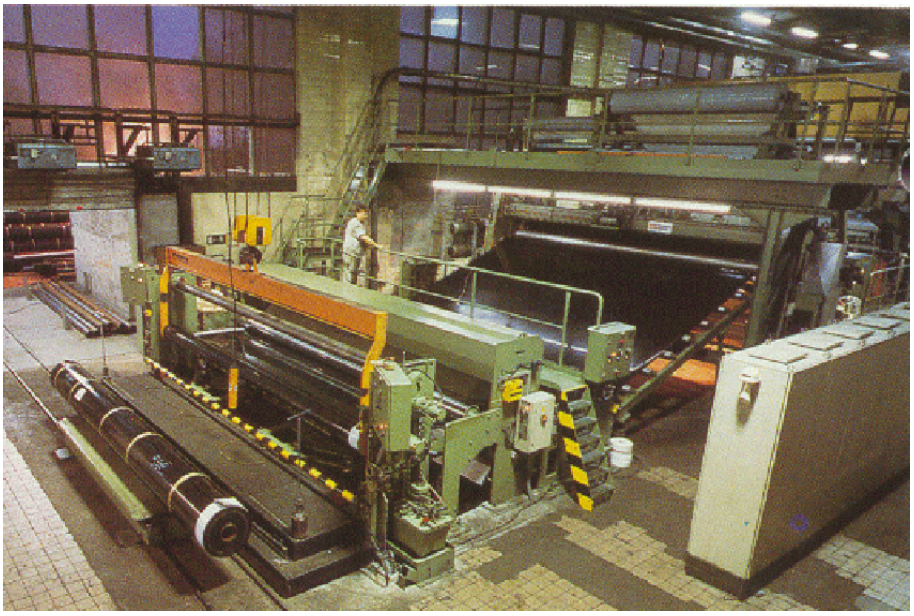


Figure 3.5 Processing of geomembranes by flat sheet extrusion.

A roughened, high-friction surface can be created on geomembranes using a process known as “texturing”. There are currently four methods used to texturise geomembranes: co-extrusion, impingement, lamination and structuring.

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Many geomembrane test methods and standards are available or are being developed by standards–setting organisations around the world. A list of the main testing standards will include ASTM, ISO and CEN. The individual test methods are grouped under the following main categories: physical properties, mechanical properties, chemical properties, biological properties and thermal properties.

3.4 Common thermoplastics used for geomembrane

3.4.1 Polyethylene

3.4.1.1 Production method and structure

PE is manufactured by polymerisation of ethylene gas under controlled temperature and pressure. The basic monomer unit of PE is shown in Figure 3.5.

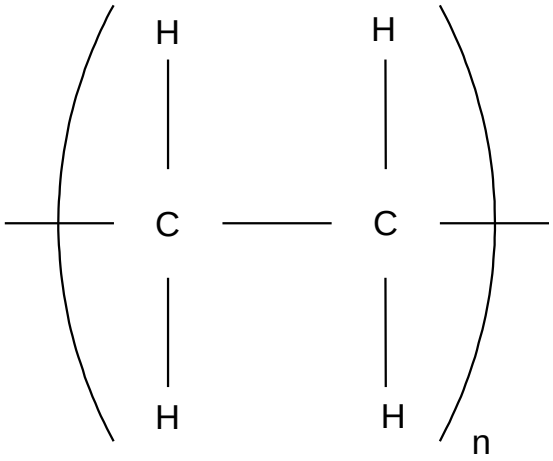


Figure 3.5 Basic monomer of PE.

Polyethylene is available in several forms, which are categorised by the density of the material. High density PE (HDPE) has a density of 941-960kg/m^3; medium density PE (MDPE) has a density of 926-940kg/m^3; low density PE (LDPE) and linear low density PE (LLDPE) have a density of 915-925kg/m^3; and very low density PE (VLDPE), also called very flexible PE (VFPE), has a density of 880-910kg/m^3.

3.4.1.2 Properties of Polythene

Polyethylenes have similar properties to polypropylenes. Polyethylenes are typically very stable and extremely durable polymers characterised by good chemical resistance and mechanical properties. They are non-toxic and can be approved for food contact applications. In general as the density increases in PE the:

- Stiffness increases.
- Yield strength increases.
- Hardness increases.
- Creep resistance increases.
- Softening temperature increases.
- Toughness decreases.

The maximum operating temperature of PE is 55°C.

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3.4.1.3 Applications

Applications of PE include:

VLDPE/VFPE	- pond liners, shrink film;
LDPE/LLDPE	- landfill site liners, roofing, landfill capping, lagoons;
MDPE	- landfill site liners, lagoons, liquid storage, water conveyance;
HDPE	- chemical storage vessels.

3.4.2 Polypropylene – PP

3.4.2.1 Production method and structure

Polypropylene, a semi-crystalline thermoplastic, is manufactured by polymerisation of propylene. There are two types of PP; homopolymer and copolymer. The copolymer is usually copolymerised with ethylene during manufacture. The chemical structure of PP has the monomer unit shown in Figure 3.6 as the basis for the homopolymer chain construction.

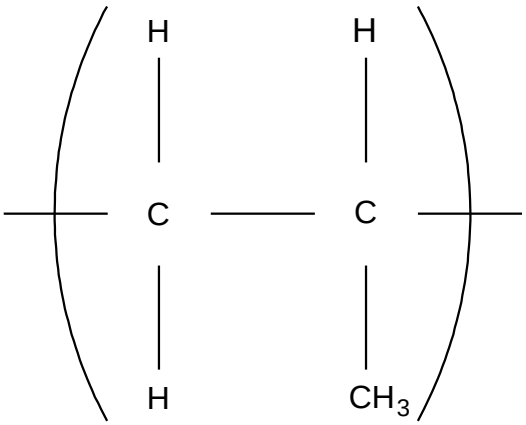


Figure 3.6 Polypropylene monomer unit.

For the copolymers, there will be a mixture of both ethylene and propylene monomers in the polymer chain. The mix will vary depending upon the grade and type.

For the copolymers, there will be a mixture of both ethylene and propylene monomers in the polymer chain. The mix will vary depending upon the grade and type.

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3.4.2.2 Properties of polypropylene

The principal properties of PP are:

Flammability	PP is flammable and ignites at a temperature around 350°C although it has a fairly slow burning rate. Flame retardants can be added.
Toughness	The toughness of PP can vary considerably depending upon the grade. The majority of grades used for fabrication are tough and fail in a ductile manner.
Processability	Simple to extrude and injection mould.
Weatherability	Like most thermoplastics, PP can rapidly deteriorate when exposed to sunlight. This can be prevented by the use of additives. For example adding black pigment to polypropylene will allow it to be stable for at least ten years in sunlight.
Resistance to solvents	PP has excellent resistance to solvents. It is therefore commonly used in solvent containment and storage systems.
Maximum operating temperature	90°C

3.4.2.3 Applications

Because of its excellent chemical and solvent resistance, PP is used in many applications where containment of these liquids is required eg fishpond liners, landfill capping, tunnel liner, water storage and sewage lagoon liners.

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3.4.3 Polyvinyl Chloride - PVC

3.4.3.1 Production method and structure

PVC is manufactured from sodium chloride (NaCl) and natural gas, with the chlorine from the salt comprising 57%wt. The chemical structure has the monomer unit shown in Figure 3.7, as the basis of the polymer chain construction.

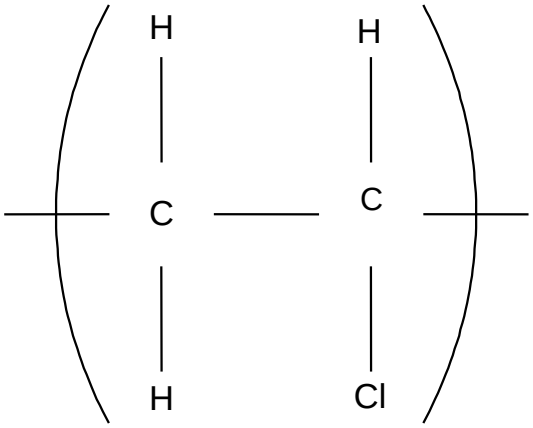


Figure 3.7 Basic monomer of PVC.

3.4.3.2 Properties of PVC

The principal properties of PVC are:

Combustibility	PVC has low combustibility due to its high halogen content (57%). Other materials often add halogens to achieve low combustibility whereas PVC naturally contains them.
Toughness	PVC compounds are usually ductile and tough and can be designed, using additives, to be virtually unbreakable.
Dimensional stability	Usually only the grades with high melt viscosity are very stable.
Processability	Simple to injection mould and extrude.
Weatherability	Some grades have poor weatherability but can usually be engineered to improve the characteristics.
Resistance to solvents	Can be poor. Some solvents are used to melt and bond the surfaces of PVC.
Maximum operating Temperature	50°C

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3.4.3.3 Process issues

When welding PVC it is important not to overheat the material since this will cause it to degrade. This is usually evident by the material turning brown and charring.

When using a hand sander with PVC, it is important to protect breathing airways with a face mask as the material produces a fine dust.

3.4.3.4 Applications

PVC is used in a wide variety of applications. Rigid PVC is used for (non-solvent based) liquid storage vessels, pipework and fume extractor ducting. Flexible PVC is used for roofing, pond liners and lagoons.

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4 Joining Techniques

4.1 Introduction

The fundamental mechanism of joining (seaming) polymer geomembrane sheets is to temporarily reorganise the polymer structure of the two surfaces in a controlled manner (ie to melt or soften) so that, after the application of pressure and the passage of a certain amount of time (speed of machine), the two sheets will be welded together. This reorganisation results from an input of energy that originates from either chemical or thermal processes. These processes may involve the addition of extra polymer in the bonded area.

Ideally, seaming two geomembrane sheets should result in no net loss of tensile strength across the two sheets, ie the joined sheets should perform as one single geomembrane sheet. However, due to stress concentrations resulting from the seam geometry, current seaming techniques may result in minor tensile strength loss compared to the parent geomembrane sheet. The characteristics of the seamed area are a function of the type of geomembrane and the seaming technique used. Designers and engineers should be aware of the importance of seeking only the highest quality geomembrane seams. The minimum seam tensile strengths (as determined by design) for various geomembranes must be predetermined by laboratory testing, knowledge of past field performance, manufacturers literature, or other standard- setting organisations that maintain current information on seaming techniques and technologies.

There are three general categories of seaming methods: thermal fusion (or melt bonding), extrusion welding and chemical fusion (or chemical adhesive). The most commonly used field seaming methods for various geomembranes are shown below in Table 4.1.

Table 4.1 Most commonly used field seaming methods for various geomembranes

Type of Seaming Method	HDPE	PVC/PVC-R	VFPE	PP
Extrusion Fillet	A	N/A	A	A
Extrusion Flat	A	N/A	A	A
Hot Air	A	A	A	A
Hot Wedge	A	A	A	A
Chemical	N/A	A	N/A	N/A
Adhesive	N/A	A	N/A	N/A

Note: A = method is applicable, N/A = method is not applicable
PVC-R = reinforced PVC

4.2 Extrusion welding

Extrusion welding is presently used on geomembranes made from polyethylene and polypropylene. Extrusion welding cannot currently be used to weld PVC. During welding, a ribbon of molten polymer is extruded over the edge of the two surfaces to be joined (Figure 4.1). The hot extrudate, together with preheat created by hot air from the nozzle which is located just in front of the Teflon (PTFE) shoe, causes the surface of the sheets to become hot and melt, after which the entire mass then cools and bonds together. This technique is called “extrusion fillet welding”. It should be noted that extrusion fillet welding is essentially the only method for seaming polyethylene geomembrane patches and for welding in poorly accessible areas such as sumps and around pipes. Temperature, pressure and seaming rate all play important roles in obtaining an acceptable bond. Too much melting weakens the geomembrane and too little melting results in inadequate flow across the seam interface and in poor seam strength. The type of resin used for the extrudate is also very important and should be from the same compound that was used to make the geomembrane. A typical symbol used to denote an extrusion weld is explained in Figure 4.2.

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Figure 4.1 Extrusion welding a patch.

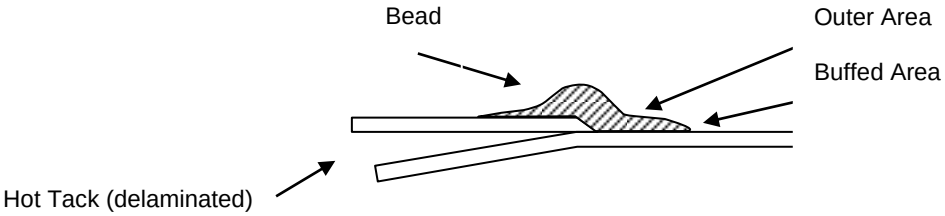


Figure 4.2 A profile of an extrusion seam.

4.3 Thermal fusion

There are two thermal fusion methods that can be used on all thermoplastic geomembranes: heated wedge welding and hot air welding. As with extrusion welding, temperature, pressure and speed all play important roles in that too much melting weakens the geomembrane and too little melting results in poor seam strength. The hot wedge or hot shoe method consists of an electrically heated resistance element in the shape of a wedge that travels between the two sheets to be seamed. As it melts the surfaces of the sheets being seamed, a shear flow occurs across the upper and lower surfaces of the wedge. Roller pressure is applied as the two sheets converge at the tip of the wedge to form the final seam. Hot wedge units are automated regarding temperature, amount of pressure applied and speed of travel. A standard hot wedge creates a single uniform width seam, while a dual hot wedge forms two parallel seams with a uniform unbonded space between them.

The hot air method makes use of a device consisting of a resistance heater, a blower, and a temperature controller to blow hot air between the two liners to be welded to melt the opposing surfaces. Immediately following the melting of the surfaces, pressure is applied to form the bond between the two sheets. Typical symbols used to denote thermal fusion welds are explained in Figure 4.3.

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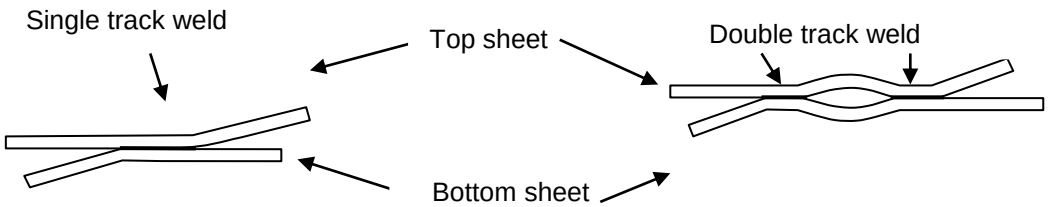


Figure 4.3 A single track and double track weld.

4.4 Chemical fusion or chemical adhesive methods

Chemical fusion seams make use of a liquid chemical applied between the two geomembrane sheets to be joined. After allowing a few seconds to soften the surface, pressure is applied to make complete contact and bond the sheets together. As with all chemical-seaming processes a portion of the two adjacent materials to be bonded is transformed into a viscous phase. Applying too much chemical liquid will weaken the adjoining sheet and applying too little chemical liquid will result in a weak seam.

Chemical adhesive seams make use of a dissolved bonding agent, known as an adherent that is left after the seam has been heated and cured. The adherent becomes an additional element in the system. Contact adhesives are applied to both surfaces to be joined and, after reaching the proper degree of tackiness, the two sheets are placed on top of one another followed by roller pressure. Chemical fusion and chemical adhesive methods are usually used when seaming PVC sheets and are not applicable to HDPE or PP geomembranes.

4.5 Mechanical fixings to concrete structures

There are two ways of fixing geomembranes to concrete structures: using a preformed profile, and steel batten fixing.

4.5.1 Preformed profile

A HDPE or PP profile is cast into the concrete at the time of pouring. The profile is fixed to the inside of the shuttering so that when the concrete has been poured and the shuttering removed a HDPE or PP face is left on part of the structure to which loose-layed membrane can be welded.

4.5.2 Steel batten fixing

Steel batten fixing is used when connecting a liner to existing concrete, eg around an existing steel pipe or when lining the vertical walls of a concrete tank. The normal steel batten dimensions are 5 by 40mm with 12mm holes at 200mm centres. It is important to have the spacing of the holes correct in order to ensure a water-tight seal between the liner and the concrete. This seal is achieved by using a neoprene gasket positioned between the liner and the concrete. When the bolts are tightened this causes the steel batten to compress the neoprene which forms the seal, see Figure 4.4.

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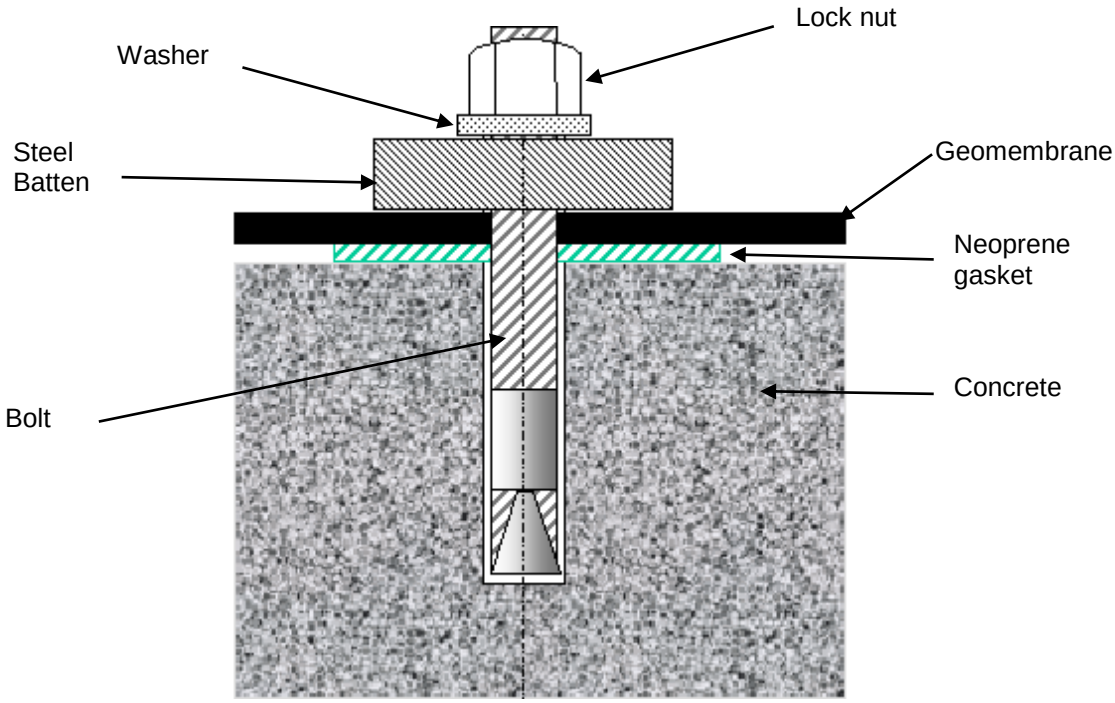


Figure 4.4 Steel batten fixing of geomembrane.

4.5.3 Checklist when fixing to concrete

- For an effective seal, the concrete must be of good quality.
- The concrete needs to be drilled to the right depth to accommodate the specified bolt.
- Stainless steel bolts should be used together with stainless steel batten where potable water is concerned.
- Bolts should not be over tightened.
- Use two different grades of stainless steel for bolts and nuts, eg A2 bolts with A4 nuts, to help prevent seizure during tightening.
- Make sure the neoprene gasket is used correctly, particularly in corners, and also that proper caulking is carried out in these areas.

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5 Thermal Fusion

5.1 Heated wedge welding

5.1.1 Introduction

There are two types of heating mechanisms for wedge welding: electric and hot air. In hot air wedge welding, heated air is introduced into the wedge, which has perforations on the top and the bottom surfaces to allow the hot air to heat both sheets to be jointed simultaneously. The area immediately in front of the wedge also benefits from being preheated by the hot air jet, which may be beneficial at times due to ambient conditions. Contamination in the form of dust is also blown away from the joint line.

The electrically heated wedge, which is far more common, is solid and contains two cartridge heaters (see Figure 5.1). The temperature is controlled by a closed loop feedback using a thermocouple positioned in the wedge. This maintains the wedge temperature typically to within ±10 °C of the set temperature during welding.

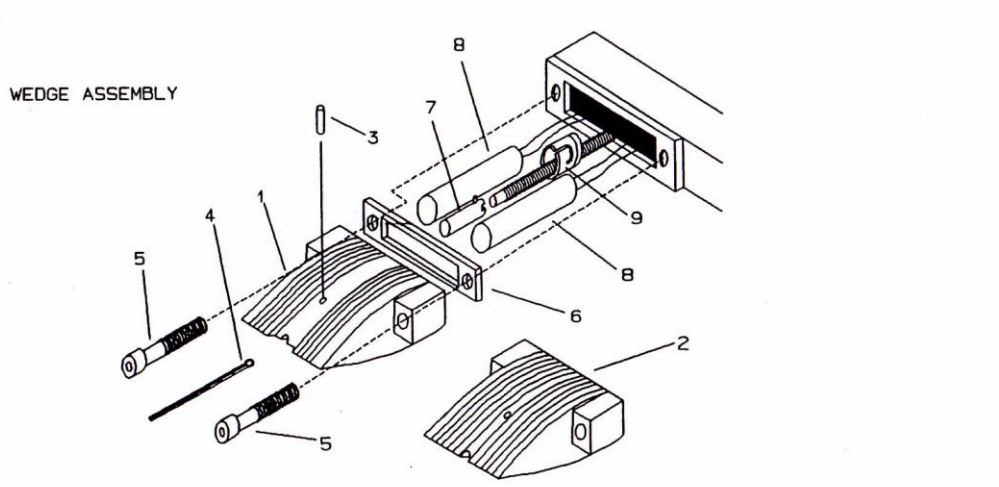


Figure 5.1 Exploded view of an electrically heated wedge assembly.

The principle of electrically heated wedge welding is that both sheet surfaces to be welded pass over, and are forced into intimate contact with, the hot surface of the heated wedge, by means of the wedge rollers, which apply pressure to the sheets against the heated wedge. The wedge lifts both overlapped sheets off the subgrade and fusion is brought about by compressing the two softened surfaces of the sheets together by means of the drive rollers (see Figure 5.2).

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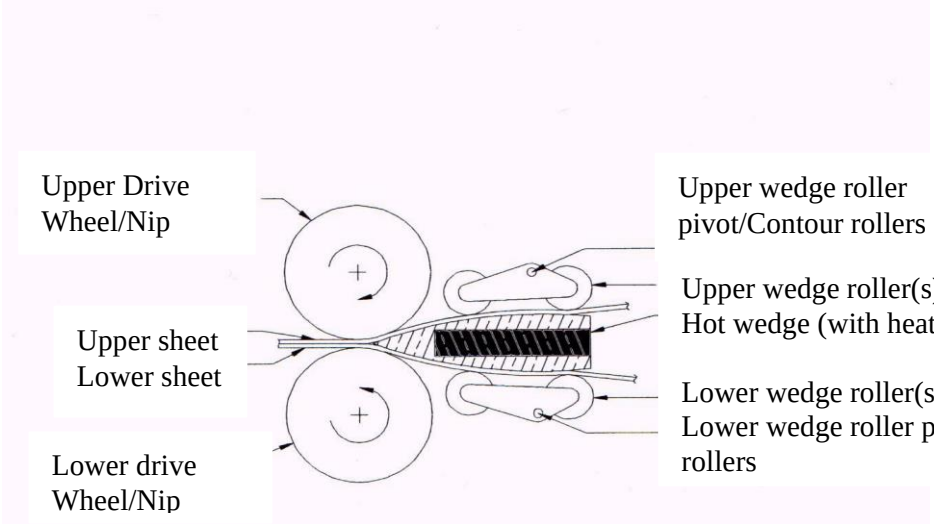


Figure 5.2 Side elevation of a heated wedge welder in a seam.

A photograph of a heated wedge welder is shown in Figure 5.3.

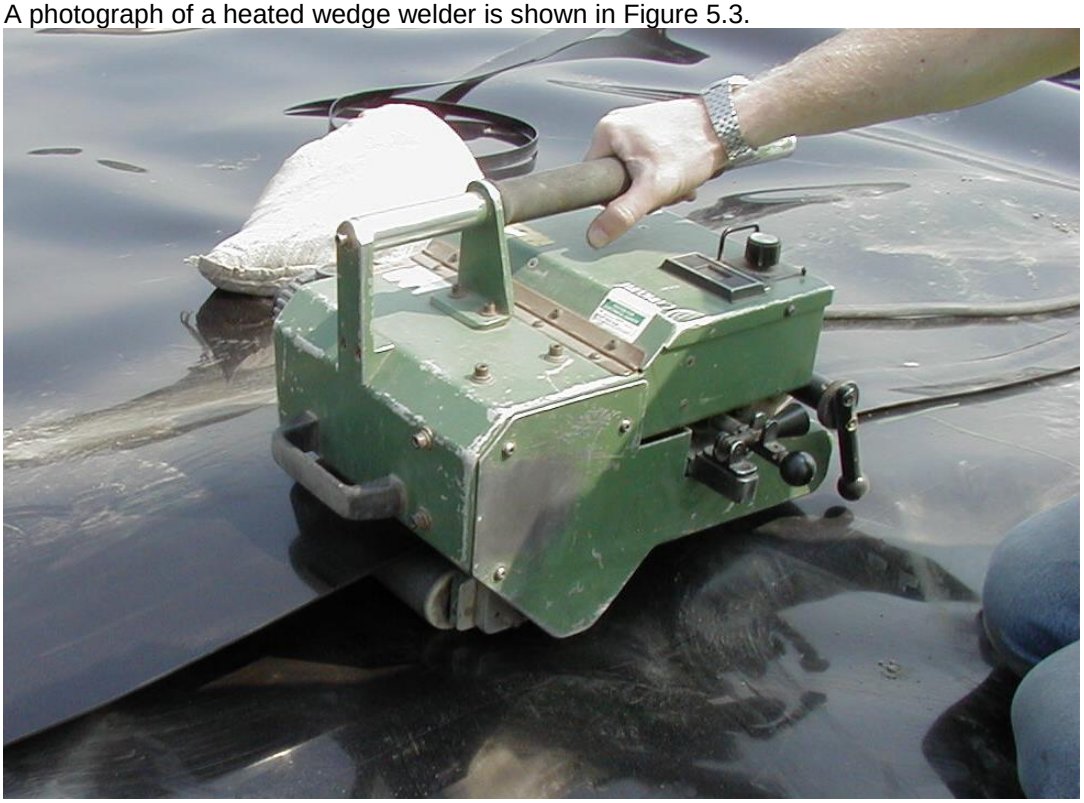


Figure 5.3 Heated wedge welder in action.

5.1.2 Joint types

Two types of joint can be produced using heated wedge welding: single seam (single track) and dual seam (double track). The dual seam, see Figure 5.4, has the advantage that it generates an unwelded channel that can be pressurised with air after the completion of the weld in order to non-destructively test the integrity of the joint (see Section 7.2.3). The geometry of the wedge used to produce a dual seam is shown in Figure 5.5, and the geometry of the wedge used to produce a single seam is shown in Figure 5.6.

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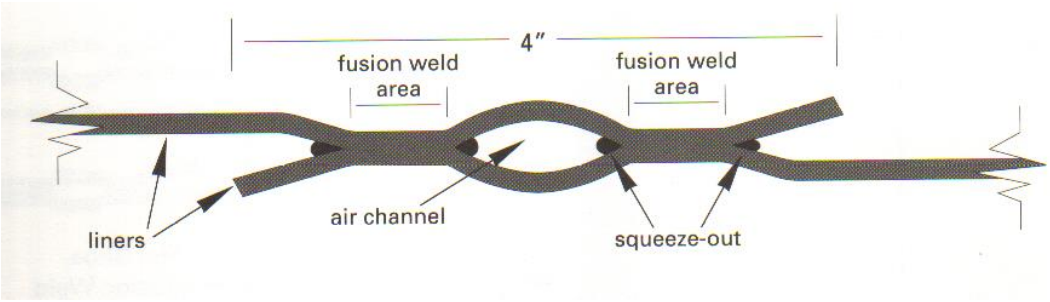


Figure 5.4 Double track fusion weld.

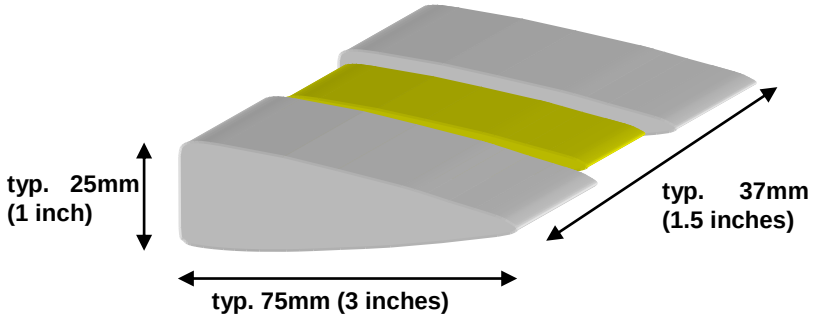


Figure 5.5 Dual (split) heated wedge.

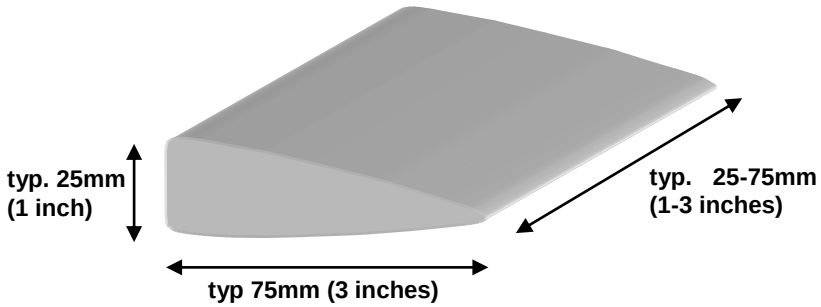


Figure 5.6 Single heated wedge.

5.1.3 Joint preparation

The most important factor in the preparation of the liner for seaming with the wedge system is the setting of the overlap. The overlap between two panels should be between 100 and 180mm and be appropriate to the make and model of welding machine being used. This overlap gives sufficient spare material either side of the weld to allow mechanical test specimens (tabs) to be cut from the seam and enable them to be easily secured in the jaws of a tensiometer.

Once the overlap has been set correctly and is ready for welding it is important that the area of the seam to be welded is clean and free from dirt and dust particles. Sometimes it may be necessary to use a water based solution such as a detergent to clean the liner. It is good practice for the operator of the wedge to carry a cotton type cloth in order to clean the seam directly in front of the wedge as the welding proceeds.
Once the correct welding parameters have been set, i.e. temperature, pressure and speed, the principle by which the liner passes over the wedge before passing through the drive

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rollers cleans the oxidation layer from the area to be welded. It is important that the oxidation layer be removed in order to ensure a good weld.

When welding textured liner to textured liner it is good practice to use what is commonly known as a “feather” fixed to the wedge in order to keep the air channel open. Without using the feather it is likely that the air channel will be closed by the excess molten material created by the welding of the textured material. Should this occur, the site CQA engineer would probably insist that the seam be extruded and vacuum box tested.

5.1.4 Positioning wedge welder in the seam

When placing the wedge welder in the seam it is necessary to feed both the top and bottom sheets into the machine from the side. This will involve tilting the machine to one side and folding the edge of the liner sheet in order to insert it correctly. Always remember to make sure that the heated wedge assembly is fully retracted during this process as it can cause burning of the operator’s hand or of the liner. Before engaging the drive rollers and pushing the wedge assembly fully forward, always make sure that the cables providing the power to the machine are free of any obstruction over the full length of the seam. Often failure to do so results in the cables snagging on something and causing the machine to stop, resulting in the hot wedge burning a hole in the liner. During the welding process, always keep a check on the temperature readouts and on the overlap, as surplus overlap will mean that the edge of the liner will have to be trimmed, if not, the machine will bind up and stop, causing damage to the liner.

Control of the overlap during welding

Geomembrane will expand significantly when subjected to direct sun light. Upon cooling, the geomembrane will contract so careful consideration of the effect of climatic conditions prior to installation commencing is important.

Once a panel of geomembrane has been deployed, the overlap distance should be constantly monitored and maintained. The natural operation of the wedge welding machine can leave a small surplice or ridge in the geomembrane. This natural surplus tends to dissipate naturally, however if the overlap increases due to expansion of the geomembrane, the small surplus will increase dramatically, leaving a distinct ridge along the line of the wedge seam. This increased ridge and surplus material can be very difficult to deal with during subsequent operation’s (ie placement of drainage stone or cover materials) and would if not managed, fold over itself forming a crease which in turn can lead to stress cracks in the geomembrane, along the edge of the fold.

Controlling of the overlap should be undertaken by trimming the edge of the top sheet with a knife. This will help to maintain the correct overlap for the type of wedge welder been used. Consideration must be taken to not cause any damage to the lower geomembrane panel. In addition, the lap should not be left too narrow as this will lead to the wedge welding machine tracking off the panel or failing to leave a sufficient tab (required for random destructive testing).

Recently manufactured wedge welding machines have spring mounted contour rollers, which have a self-calibrating function. However when wedge welding wide panels, where the overlap is allowed to be greater than suitable for the machine, the spring loading can yield to the lateral force in the geomembrane panel resulting in the weld surface losing full contact with the heated wedge surface. This will result in insufficient heating of the geomembrane and random weld failures.

Figure 5.7 shows a typical wedge welder in action.

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Figure 5.7 Wedge welding a seam.

5.1.5 Equipment cleaning and maintenance

The welding machine operator must clearly understand that the welding equipment can only function properly if correctly calibrated and maintained. It is important that the drive rollers are disengaged before the welder completes the seam, in order to avoid damaging the tips of the heated wedges. This simply means that the operator releases and removes the wedge, once he has reached the end of the seam, not before and not after. Once the wedge welder has been removed from the seam, the operator should clean the wedge and the rollers thoroughly by using a wire brush.

If the subgrade is wet during welding, it will cause the machine to pick up dirt during the welding process and, if this is not removed at the end of each seam, it may cause problems with the set up of the machine. Care should also be taken with the electrical cables, to ensure that they are not strained as a result of snagging on a sand bag or ballast which may have been used during the installation, or on any other object that may be in the vicinity. If the welding machine gets wet for some reason during the seaming process, it is important that the electrical components are checked and dried thoroughly in order to prevent short-circuiting. It is also important to keep the wedge clean and dry at all times as moisture can cause the cartridge to become faulty. It is good practice to regularly check the actual temperature of the wedge by means of a temperature probe placed directly on the face of the wedge.

5.1.6 Checklist for wedge welding

Set-up

- Set nip compression rollers to proper width dependent on material thickness.
- Set wedge welder to centre the hot wedge between the nip rollers.
- Set temperature control to suggested starting temperature range.
- Set speed control to achieve a quality weld.
- Set and maintain the proper geomembrane overlap.

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- Ensure surfaces are clean and free of moisture.
- Determine if a protective barrier (ie rub sheet) is necessary due to subgrade conditions.
- Determine if weather conditions are appropriate for welding.
- Inspect the forward face of the welding machine for sharp corners and irregular details that may damage the liner as the machine moves forward during the seaming process.
- A small amount of “squeeze-out” is a reliable indication that proper seaming temperatures have been achieved. Excessive melt or geomembrane sheet wrinkling indicates that excessive heat or pressure or both may have been applied. Adjust temperature and/or pressure to correct the situation.

Operation

- Ensure that the equipment operates within the acceptable temperature and speed parameters.
- Monitor the temperature readout and speed of machine.
- Ambient variables such as temperature, cloud cover, and wind speed may make it necessary to adjust wedge speed due to effects on membrane temperature during welding.
- On soft subgrade the welding machine may tend to “bulldoze” into the ground as it travels, causing soil to enter the weld. The operator should slightly lift the front of the welding machine to avoid this situation or use a sled or rub sheet.

5.2 Hot air welding

5.2.1 Introduction

The hot air method of welding makes use of a device consisting of a resistance heater, a blower and a temperature controller to blow hot air between two sheets of liner to melt the opposing surfaces. Immediately following the melting of the surfaces, pressure is applied to form the bond between the two sheets. As with the heated wedge method, both single and dual track welds can be produced.

5.2.2 Machine welding

For the automated type of hot air seaming equipment there are a number of important details. As with the hand held torch, adequate airflow is important and with the nozzle in place, the temperature should be checked to ensure that a constant flow of air at the correct temperature is being supplied. A simple way of checking this is to place your hand in front of the nozzle to check for airflow. Once you have done this a few times, you will be able to recognise adequate airflow.

There are two types of airflow nozzle for the automatic machine; one for producing a single track and one for producing a double track seam. If a double track seam is required the nozzle is subdivided at its exit end into two separate airflow channels. As with the hot wedge welder, knurled rollers are used to drive the device and to apply pressure to the liner. They immediately follow the air nozzle. A drive motor, utilising a chain drive system similar to the wedge welder, powers the rollers. As the liner sheets pass through the machine, they should come into contact with air from the full width of the air nozzle in order to heat the material properly and uniformly. On some machines, guide rollers on both sides of the device are adjustable and help the material to pass through the machine. Temperature controllers on the machine should be set according to the type of geomembrane sheet being welded, the ambient temperature and the rate of seaming.

5.3 Welding parameters

The three important parameters in heated wedge welding are temperature, pressure and speed. It is therefore important that the welding technician understands how to set and control each parameter.

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5.3.1 Temperature

All types of geomembrane welding require clean and dry conditions. The ambient temperature, cloud cover and moisture are all crucially important to welding, as is the wind speed. High winds or gusts are problematic because liner panels can be displaced, and wind also has a cooling effect on the wedge or hot air. Wind can also blow dust or dirt into the seam being welded. The setting of the welding parameters will depend greatly on the ambient temperatures. It is therefore very important for a test seam to be carried out within the location of welding, at the start of each period of welding activity (generally morning and afternoon). Additional test welds should be carried out if there is any dramatic change in climatic conditions within the location of welding work.

Ambient temperature will have an affect on the speed setting on the wedge. As the ambient temperature falls the temperature of the geomembrane also reduces, which means the geomembrane will require additional heat from the heated wedge block on the machine to reach its optimum melt temperature. This is achieved by slowing the wedge welding machine travel speed so the surface of the geomembrane has longer contact time with the wedge block. As the ambient temperature rises, it will have the opposite effect, in which case the speed will have to be increased in order to avoid overheating of the geomembrane within the seam. It is therefore important that the operator or technician constantly monitors the temperature and performance of the wedge welder and on the overlap of the section to be welded so that he can make adjustments when necessary in order to maintain a consistent weld.

The subgrade on which the liner is placed needs to be free of any ponded water and firm. It is not possible to carry out any welding procedure in wet conditions because in such conditions the correct relationship between the welding parameters cannot be controlled.

A range of welding temperatures for the various materials can be seen in Table 5.1.

Table 5.1 Typical welding temperature ranges for wedge welding common geomembrane materials.

	Welding temperature, °C	
Geomembrane Type	Minimum	Maximum
HDPE	350	400
PVC	270	370
VFPE / LLDPE	350	400
PP	350	400

5.3.2 Pressure

The pressure necessary to produce a good weld is provided by adjusting the nip, or drive rollers as they are known. The pressure setting will vary depending on the thickness of the material to be welded. The drive rollers have an embossed surface to assist with grip and, for dual seam welds, a good indication of balance between each track of the weld is that the roller indentations on both weld tracks on the surface of the liner should be similar. Adjustment of the drive rollers is usually by means of a turn screw. For most machines, the pressure is set by adjusting the drive rollers with two pieces of membrane to be welded in a feeler gauge fashion between the top and bottom rollers. The final adjustment is then made by means of the turn screw and a visual inspection of the impression on the liner created by the knurled rollers. If the roller marks are uneven, it indicates that the pressure setting is uneven. If the roller marks are very heavy or deep, it indicates that there is too much pressure. The ideal situation is for a slight impression on the surface of the liner, which looks the same on both tracks.

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The wedge contour roller setting is very important in the calibration of the wedge welder as its function is to guide the liner to be welded smoothly over the heated wedge, ensuring that the two are in intimate contact before passing the liner through the drive rollers. If the wedge contour rollers are stiff or incorrectly adjusted, then there may be cold spots on the liner that could cause a defect. Wedge welding machine design has moved forward significantly in recent times with some manufacturers including a self calibrating spring mounted contour roller design. Caution should be taken when welding wide panels because if an overlap is allowed to be greater than suitable for the machine used, the spring loading can be applied to the panel, resulting in the heated wedge losing contact with the material surface. This can result in a reduction of temperature at the weld surface and random weld failures.

5.3.3 Speed

The speed of the wedge welder is set by adjusting the motor that controls the drive rollers, by adjusting the dial on the wedge machine upwards or downwards. The welding speed will typically be in the range of 0.7m per minute up to 4.0m per minute depending on the thickness of the membrane being welded and the ambient conditions. The thicker the sheet, the slower the welding speed.

5.4 Reporting

5.4.1 Manual reports

The liner installation trial weld report and the liner installation weld report, as shown in Figures 5.8 and 5.9, respectively, form the basis of the manual records that should be recorded on a daily basis by the installation team. It is the installation company's responsibility to ensure that they retain these records within their own completed site file, independent to the CQA's records. This information will be requested by the site CQA engineer and will be incorporated into his CQA report, which he will prepare on behalf of the site owner on completion of the project. The information contained in these reports will also be invaluable to the installation contractor, as it will indicate how efficient and quality conscious the installation crew were, at any given time during the contract. In addition to these checks, manual reports are retained by the installation company and are randomly examined as part of the company accreditation scheme auditing procedure.

5.4.2 Automatic reports

On some types of wedge welding equipment, there is a facility to use a printer, which provides an accurate printout of the variable parameters during the seaming process. In the UK, while there are some welding machines in use that can be fitted with a computer printout, this technology is currently not used. In time it is probably safe to say that this technology will not be required in the UK as it will undoubtedly add significantly to installation costs.

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Liner Installation
Trial Weld Report

Project: _____

Date	Time (24 H)	Machine No. Ext./Fus.	Welding Technician Initials	Wedge/ Extrudate Temp(ºc)	Speed/ Pre-Heat (m/min)/(ºc)	Ambient Temp (ºc)	Wind* (S/L/M)	Peel Test (No.)	Shear Test (No.)	Trial Seam Acceptance (QAM Intl)

* S – Still L - Light M – Moderate

Figure 5.8 Example of a liner installation trial weld report.

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Liner Installation
Weld Report

Project: _____

Date	Time (24 H)	Seam Ref.	Machine Ref. Ext./Fus.	Welding Technician Initials	Wedge/ Extrudate Temp(ºc)	Speed/ Pre-Heat (m/min)/(ºc)	Ambient Temp (ºc)	Wind* (S/L/M)	Non-Destructive Testing Passed	
									Date	(QAM Intl.)

* S – Still L - Light M – Moderate

Figure 5.9 Example of a liner installation weld report.

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6 Extrusion and Manual Hot Air Welding

6.1 Principles of extrusion welding

6.1.1 Introduction

The principle of extrusion welding differs from wedge welding in that the extrusion weld is a surface weld. It involves the introduction of molten plastic, in the form of a ribbon, which is extruded from a hand held welding gun, to the area to be jointed. This ribbon fuses with the geomembrane sheet to form a homogeneous bond.

As with the wedge welder the parameters required to ensure a good weld are the correct combination of temperature, pressure and speed. A diagram of an extrusion seam is shown ***below in Figure 6.1.***

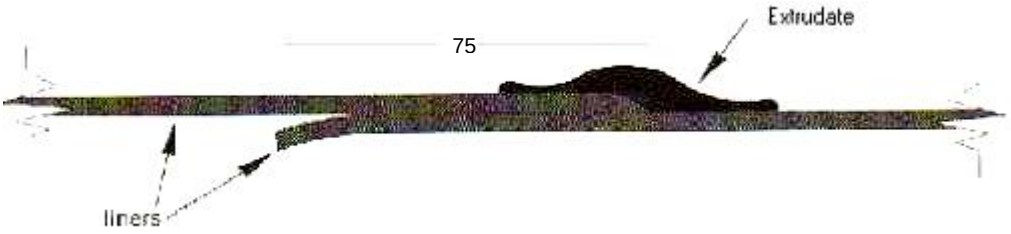


Figure 6.1 Diagram of an extrusion seam.

The extruded ribbon is formed by forcing the molten plastic through a brass nozzle with a small aperture at the end of the welding gun, which creates a back-pressure. The melt then passes through a heat-resistant Teflon shoe, the face of which is shaped to give the profile of the weld, which is generally a crown shape, ie there is more material in the centre than on the edges. The typical temperature of the molten plastic (extrudate) as it comes out of the extrusion gun is 235°C. This temperature is produced by a heater band around the barrel of the extrusion gun and is controlled using a thermocouple connected to a temperature controller in a closed loop feedback system. This maintains the temperature to within 10°C of the set temperature during welding.

6.1.2 Feed systems

6.1.2.1 Introduction

Two different types of feed system are used for extrusion welding: a rod (wire) feed and a granulate feed. The most commonly used system currently is the rod-fed machine. However, the granulate fed machines are still used and preferred by some installers because they are more versatile in certain situations. From a material usage or wastage point of view the rod fed machine is more efficient, as the rod is normally supplied on a coil whereas the granulate fed machine utilises a hopper as the reservoir for the granulate. In a working situation on site the hopper can topple over and the granulate becomes contaminated with dirt or moisture and can no longer be used. Photographs of both types of extrusion welder are shown in Figure 6.2.

6.1.2.2 Granulate and welding rod

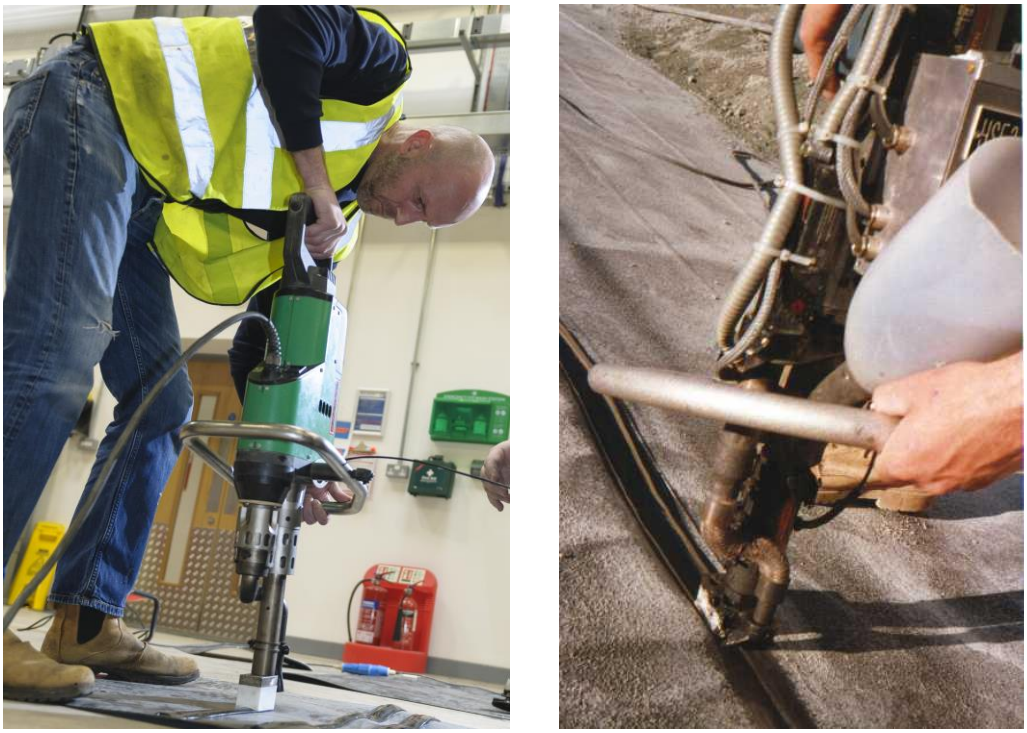
Welding membranes using welding rod or granulate from different suppliers is the most common reason for poor or inconsistent welding results. It is important that granulate and welding rod used for extrusion welding is manufactured from the same resin type as the membrane to be installed. It is also important that it is from the same manufacturer as the membrane and produced by the same manufacturing facility. Slight variations in resins could result in the operator using welding materials with different melt flow indexes (MFI). The MFI of resins can vary dependant on their source globally, as membranes from a manufacturing facility in one region, may differ from membrane or rod from the same

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supplier from a different region. In this instance, it can also be difficult for the operator to achieve satisfactory weld strengths.

If materials from different suppliers are to be used (typical when carrying out tie in welds to existing membrane installations) then a reasonable number of test samples should be taken from trial welds to prove that the weld strength and failure mechanisms are satisfactory.

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a) **b)**

Figure 6.2 Photographs of both of types of extrusion welding guns:
a) rod-fed
b) granulate-fed.

6.1.2.3 Rod feed

Rod-fed extrusion welding (sometimes known as wire welding) refers to the use of a coil of plastic rod, in diameters of 3 to 5mm, as the material that will be melted in an extrusion gun to form the molten ribbon. Rod-fed machines are very versatile in that they can be used for complicated installation details, which may require them to be used at a variety of angles, including overhead.

6.1.2.4 Granulate-fed

The granulate-fed welding machine is the original of the hand held extrusion guns and is still widely used today. It consists of a reservoir of granulate pellets which feed into the barrel of the extrusion welding machine. The granulate is the same material used to make the parent sheet and is delivered to site in drums or bags. The granulate-fed machine is not as versatile as the rod feed machine as it depends on gravity to feed the granulate into the machine.

6.1.3 Operation of the equipment

It is important that trial welds are always performed prior to actual field seaming in order to ensure that the welding machine and the welding parameters are correctly set. It is important that any trail welds are carried out within the work area that field seaming welding is to be undertaken and should be repeated if there is any change in climatic conditions. At least five destructive test specimens (tabs) should be taken from the trial weld and tested prior to beginning fieldwork, to ensure that the necessary mechanical properties have been met. The lowest ambient temperature at which welding can take place is the lowest temperature at which a fully compliant weld can be achieved. For sheet temperatures below 0°C, shielding, pre-heating and/or a slower seaming rate may be required. This will reduce the impact of sudden temperature changes within the material and reduce the risk of brittle weld failures and low weld strengths. In this instance more frequent seam testing will also

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be necessary. Due to the fact that two of the welding parameters (speed and pressure) are determined solely by the operator, all field welding must be carried out by the same technician that undertook the pre-start trial weld. If a different technician is to carry out site welding he must also undertake a successful trial seam and log the results appropriately.

Before beginning a trial weld or an actual field seam, the extrusion welder should be purged of all old extrudate that may be in the barrel. This must be done every time the extruder is restarted after a two-minute or longer period of inactivity. The purged extrudate should not be discharged on to the surface of previously placed liner, nor on the prepared subgrade, where it would eventually form a hard lump under the liner causing a stress concentration and possibly puncturing the membrane.

Once the machine is up to temperature and the operator is ready to begin welding he needs to ensure that there is sufficient heat coming from the preheat nozzle. A good way to do this is to place your hand in front of the hot air nozzle to establish a flow of air and whether it is hot or cold. Modern extrusion welding equipment constantly monitors both the pre heat and extrudate temperature. If either temperature falls below the pre-set minimum requirement, the extruder will cut the power to the drive motor, preventing the machine from operating (this is another example of the need to use the correct type of welder for on-site welding). The solid extrudate in the Teflon shoe also needs to be removed each time the operator begins welding. When starting a weld the operator needs to ensure that he preheats the area where he is proposing to start, as a cold start can lead to a defect in the seam.

During the seaming process an extrudate ribbon of molten polymer is deposited over the overlapped geomembrane. The centre of the extrudate must be located directly over the edge of the upper geomembrane. If the sanding has been carried out correctly, the extrudate should cover the sanding marks on each side of the upper and lower geomembranes to within 0.6cm of the outside borders. The extrudate thickness should be twice the fml sheet thickness measured from the top of the upper sheet to the top (or crown) of the extrudate. See sketch attached, Figure 6.3.

The shape and depth of the extrudate is determined by the shape of the PTFE shoe. The shoe has an effect on both forward speed of the extruder and projection of heat into the welded area. The shoe should be shaped to leave a minimum depth of twice the thickness of material been welded. The surface of the shoe should be smooth and free from scratches on the surface. The leading and trailing edges of the shoe should also be rounded off to enable the shoe to move over undulations in the welding surface. The resultant weld should be smooth with no signs of material dragging.

The shaping of a Teflon (PTFE) shoe on an extrusion welder is very important; the shape and depth have a great impact on the overall performance of the weld. Typically, replacement shoes from equipment suppliers are pre-shaped for undertaking fabrication fillet welds and give a weld profile not suitable for extrusion welding of geomembrane. It is therefore necessary to reshape the Teflon shoe prior to use.

Importantly, it should be noted that fine dust particles given off from machining PTFE, can be harmful to humans lungs and suitable precautions must be taken to prevent inhalation of the dust.

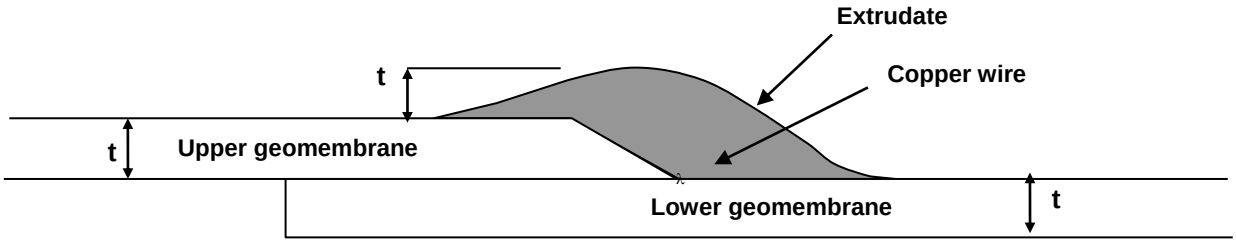


Figure 6.3 Cross-section of a good quality extrusion weld.

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Squeeze-out, as shown in Figure 6.4, is acceptable as long as it is properly joined with the geomembrane and is equivalent to the squeeze out on the trail seam. Visual inspection of the squeeze out can be used as an indicator that the extruder is been operated with the same pressure and forward speed as used in the trial test. Squeeze out will interfere with subsequent vacuum box testing so should be kept to a minimum and not exceed 5mm. Excessive squeeze-out generally means that the PTFE shoe was not sitting directly against the geomembrane, the seaming rate was too slow or the extrusion temperature was not correct for adequate flow. It is also important that the appearance and shape of the extrudate represents that of the trial weld.

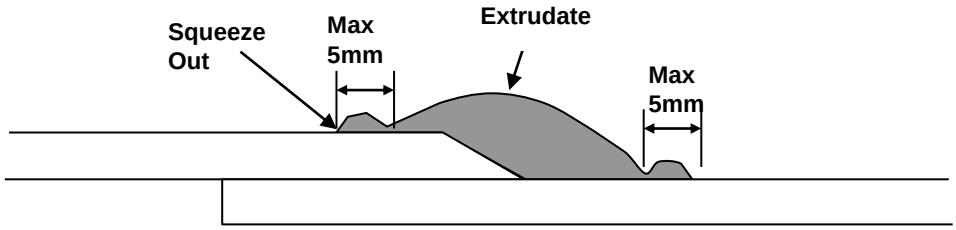


Figure 6.4 Cross-section of extrusion weld with acceptable squeeze-out.

If the extrusion seaming needs to be interrupted at mid-seam the extrudate ribbon should end abruptly with the extrudate being no thicker than in a normal weld, and not with a large mass of solidified extrudate. Where extrusion welds are temporarily terminated long enough to cool, they must be sanded prior to applying new extrudate over the existing seam. If this procedure is not followed then the area of the weld between the new and the old ribbon will be a potential leak site. It is important that this restart procedure should be adhered to whether a technician is welding a seam, a patch, pipes, fittings, appurtenances, or T and Y shaped seams.
When the operator reaches the end of the seam or reaches the end of the section he is welding, over an existing seam, it is good practice to maintain pressure and forward movement on the machine for a few seconds after he has turned off the motor, so that the hot extrudate will finish smoothly.

After seaming, visual inspection of the extrudate should be made, particularly for straight-line alignment, height, and uniformity of surface texture. There should be no bubbles or pock marks in the extrudate. Such surface details on the extrudate indicate the presence of air, water or dirt within the feed rod or granulate. Typical temperature settings for extrusion welding are shown in table 6.

Table 6 Typical temperature settings for an extrusion welding machine

Geomembrane type	Preheat minimum	Preheat maximum	Melt / Extrudate minimum	Melt / Extrudate Maximum
HDPE	200	280	210	245
PVC	N / A	N / A	N / A	N / A
VFPE / LLDPE	200	265	200	235
PP	200	275	200	235

6.1.4 Checklist for extrusion welding

- Set recommended or correct preheat temperature.
- Set barrel extrusion temperature to the recommended or correct temperature required for the welding material.
- Allow the equipment to heat up according to the manufacturer's instructions.
- Ensure the welding rod or granulate is clean and dry.

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- Purge the extrusion welder before starting welding..
- Ensure the geomembrane is clean and dry.
- Ensure extrudate is centred over the exposed geomembrane overlap edge.
- Ensure visible sanding marks beyond the edge of the extrudate are limited to 6mm maximum.
- Select the extrusion shoe necessary to provide the bead cross section required. The extrudate depth at centre should be a minimum of twice the sheet thickness. Also, the angle of the shoe needs to match the joint geometry – flat, corner, angle, etc. Squeeze-out is acceptable providing it is no more than 5mm wide.
- When possible, after welding inspect the underside of the lower liner for heat distortion. This can be done at the end of the seam and/or wherever destructive samples are taken. Slight puckering on liners 1.5mm and less is acceptable. For liners greater that 1.5mm no puckering should take place. Adjust temperature or speed of seaming to correct the problem.

6.2 Joint preparation

6.2.1 Tacking by manual hot air

For extrusion welding on a patch repair, the minimum overlap (from edge of damage to outer edge of the patch) is 150mm. The minimum overlap is 100mm for adjoining two adjacent geomembrane panels by extrusion seam welding.

This overlapped material must be cleaned in a similar fashion to the preparation for wedge welding ie with a water based solvent or by means of a clean dry cotton cloth.

The next step in preparing the joint is to tack the two sections of liner to be welded in order to prevent movement during the subsequent sanding and extrusion welding. This is done using a hot air welding torch. The most common type of hand held hot air welding torch consists of a blower and a barrel, which contains a heating element. The barrel can be fitted with various shaped nozzles depending on the type of work being undertaken.

The element in the hot air torch is typically rated at 1400W and can create an air temperature up to 600°C. For tacking PE or PP geomembrane under normal conditions, an air temperature of 320-340°C, measured using a thermocouple placed 5mm in front of the nozzle, is recommended.

The principle of the technique is that hot air is introduced between the two sheets being tacked by means of a flat (fish-tail) nozzle of the hot air torch, which melts the surfaces. The nozzle is moved along at a constant speed and pressure is applied immediately behind the nozzle by means of a hand held roller or other blunt instrument that will not damage the liner. The combination of hot air and pressure results in the tacking of the two sections of liner together.

The welding temperature and rate of seaming will vary according to the geomembrane type, the thickness and ambient conditions, such as temperature, cloud cover, wind speed and humidity. They will also depend on the amount of detail involved, i.e. whether it is a straightforward seam, a patch, or a detail around a structure or pipe, etc. Excessive melting or surface deformation, indicating too much heat or too slow a travel rate, is obviously not permitted.

On completing the tack weld the following observations should be made:

1) Check that the patch has been properly secured around the whole of the outer edge.
2) The patch is flat to the underlying geomembrane (no puckering, creasing or fish mouths have been created).

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If any of the above are visible, then the procedure should be undertaken again with a new piece of patch material, this time allowing an additional 150mm minimum distance from the external edge due to damage caused by the initial tack-welding attempt.

6.2.2 Sanding

In order to ensure that the extrusion weld is of the highest standard with no defects present, it is important to chamfer the edge of the membrane surface (as shown in diagram 7.7). This procedure can be undertaken prior to or after the patch has been tacked. When undertaking this process after tack welding, great care must be taken not to oversand and dramatically reduce the thickness of the lower membrane, as this will introduce a failure mechanism and produce a weak weld. The width of the finished extrusion ribbon should be considered before sanding the weld area, as the width of the sanded area should never be less than the ribbon width. In addition, no more than 6mm of sanding should be visible on completion of the extrusion weld.

Sanding a patch prior to welding, using a hand-held sanding machine with an abrasive disc, is shown in Figure 6.6.



Figure 6.6 Chamfering the edge of the top membrane after it has been tacked.

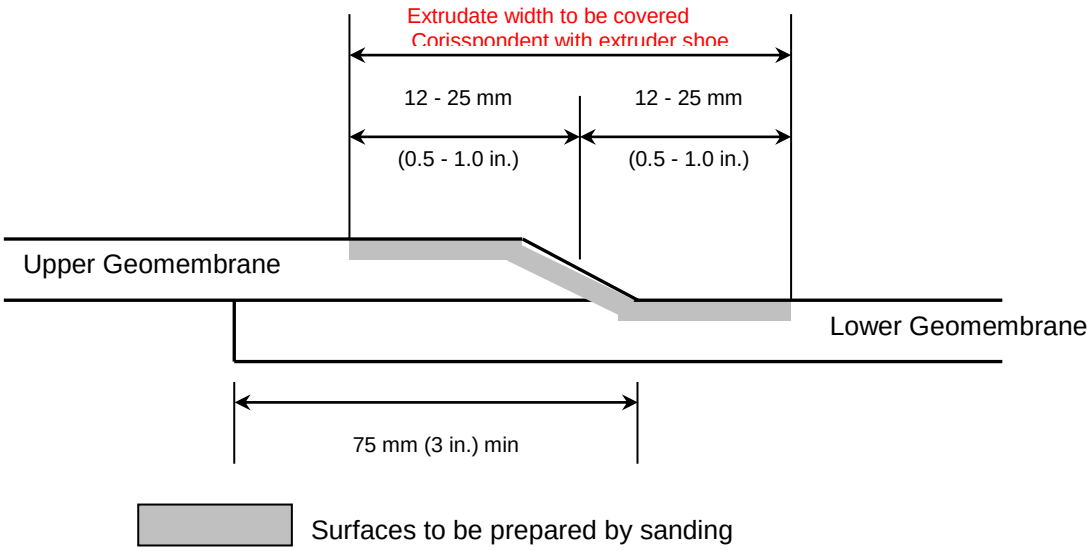
In addition, it is necessary to remove the oxidised layer on the liner in the area to be jointed before applying the extruded ribbon to the seam. Again, this is done using the hand-held sander. The oxidised layer is an invisible film over the entire surface of the geomembrane formed as a result of exposure to the elements. It is important that the sanding is performed correctly in terms of the depth and the width of the sanding in relation to the thickness of the geomembrane and the width of the extruded ribbon. Typical sanding parameters are given in Figure 6.7. It is important that the sanding marks should not extend more than 6mm outside of the extruded ribbon once the weld has been completed. All of the material that has been sanded from the geomembrane sheets must be blown away from the seaming area.

The depth of the sanding marks is extremely important. Initial sanding depths should be targeted to be less than 5% of the sheet thickness. Areas where sanding depths are greater than 10% should be cut out and replaced. It is important to remember that the objective of sanding is to remove the oxidised layer and waxes from the geomembrane surfaces. The sanding should produce a fine-grained smooth surface.

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Figure 6.7 Sketch of typical sanding parameters.

It is important to remember that welding should take place as soon as possible after sanding so that oxidised surface layers are not recreated before placement of the extrudate, and also to prevent dirt or dust from embedding into the sanded area.



Some important points to remember when sanding are:

- The sanding disc should be approximately 100 – 150mm in diameter.
- #80 grit sandpaper should be used, or #100 grit if the membrane is less than 1.0mm thick.
- Sandpaper coarser than #80 can leave deep grooves in the weld area which represent potential defects.
- Sanding marks should never be deeper than 10 percent of sheet thickness and should extend less than 6mm on either side of extrudate after welding.
- Welding of the seam should ideally be carried out within one hour of sanding
- Sanding should not melt the prepared surface.

6.2.3 Insertion of copper wire for spark testing#

The copper wire that is used for spark testing (see Section 7.2.2) can be inserted into the joint using a number of different techniques:

- A hot air welding torch fitted with a wire-welding (speed) nozzle (see Figure 6.8).
- A hot air welding torch using the edge of a fish-tail nozzle.
- By hand, during the extrusion welding operation.

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Figure 6.8 Inserting the copper wire using a speed nozzle.

The correct position of the wire in the joint is shown in Figure 6.3. It is important that the seam to be welded is tacked and sanded before the copper wire is inserted, in order to avoid damaging the wire prior to welding. Care should be taken not to reduce the membrane thickness, during this procedure, as this will result in a reduction in joint strength. The wire acts as a conductor of electricity during the spark test and should the wire be broken then obviously the spark test cannot be completed.

The temperature of the hot air gun, when placing the copper wire should be approximately 250-300°C, measured 5mm from the nozzle in the centre of the air stream. The operator needs to move the hot air gun along the seam quickly, in order not to damage the membrane. In a situation where the copper wire breaks during installation or at the junction between an old seam and a new seam, it is important to overlap the new section of copper wire with the existing one, in order to ensure continuity.

6.3 Applications for extrusion welding

6.3.1 Repairs

6.3.1.1 Introduction

In general the geomembrane will need to be repaired for one of three reasons:

- Mechanical damage to the geomembrane caused by sharp objects or by mechanical equipment on site.
- Test specimens taken from the actual seams for third party destructive testing.
- Defects shown up during non-destructive testing.

There are two methods of carrying out repairs:

- Extrusion welding directly over the existing welds or defects, in the case of an indentation in the liner or a pinhole.
- Extrusion welding a patch over the damaged area.

6.3.1.2 Direct extrusion welding

When repairing a pinhole or indentation in the liner, it is necessary to sand the area to be repaired extending at least 75mm around the damaged area. The extrusion bead will be

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laid down in the same manner as for normal extrusion welding and cover the sanded area completely.

6.3.1.3 Welding a patch

If the defect is anything bigger than a Indentation (i.e you can visibly see though the geomembrane), then a patch is necessary. The patch should extend at least 150mm outside the damaged area in order to ensure that the damaged area is covered completely. The patch should then be prepared and welded in the same way as a normal extrusion weld, placing the copper wire around the patch and ensuring that the wire makes a complete circuit for the spark test.

6.3.1.4 Repair procedures

- Patch size (overlap must be minimum of 150mm from extent of the damage).
- Trace failed destructs 3m per side of failed samples and retest seam. Cap strip length of seam between two passing destructive samples.
- Avoid trapped air under larger patches.

6.3.2 Connection of pipes

In many lining projects there will be a requirement to seal directly to a pipe. When sealing to a pipe, which may have a wall thickness several times greater than that of the geomembrane material (eg connecting a 2mm liner to a pipe with a 20mm wall thickness) the preheat necessary for an extrusion weld to the pipe will damage the liner long before it will damage the pipe. In this situation, the best way to seal to the pipe is to weld a section of stock sheet around the pipe first. Stock sheet refers to a slab of material, which can be bought in various thicknesses. The selection of the stock sheet will depend on the thickness of the pipe wall to which it is being connected, ie a 20mm stock sheet should be chosen for connection to a pipe with a 20mm wall thickness. In simple terms, a hole is cut in the stock sheet using a jigsaw and the pipe is placed through the hole, see Figure 6.9. The pipe should be a tight fit in the hole. The welding of the pipe to the stock sheet can only be by the extrusion method and obviously both must be of the same material. There are specially shaped Teflon shoes that can be fitted to the extrusion gun in order to fit snugly in the angle between the pipe and the stock sheet. Once the stock sheet has been successfully welded to the pipe, the geomembrane can be extrusion welded to the stock sheet in the normal way. A photograph of a seal around a pipe is shown in Figure 6.10.

The use of stock sheet is optional and is dependent on the design criteria and site conditions.

It is not normally a requirement to weld a thin geomembrane to a thick-walled pipe. It is normal to have a mechanical seal only.

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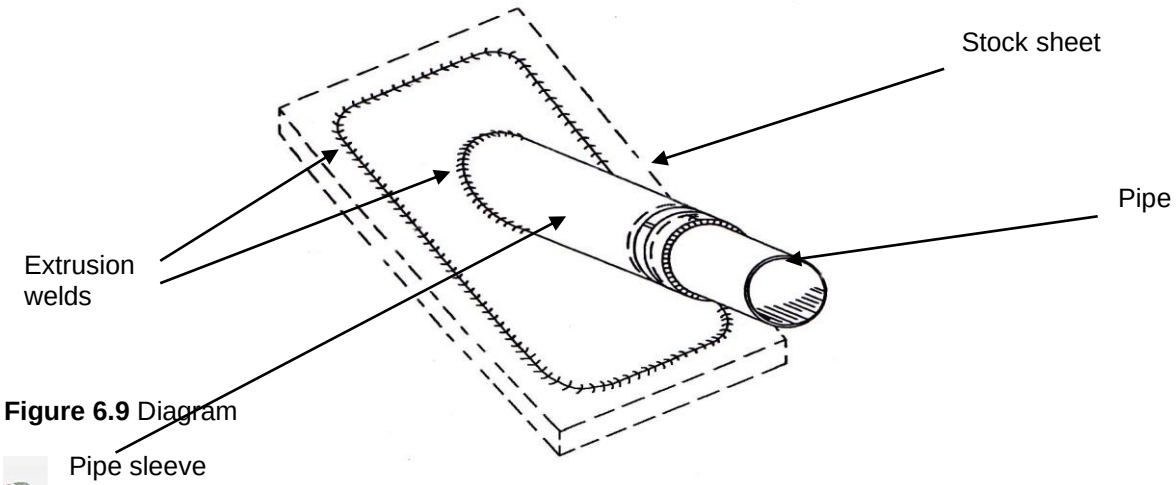


Figure 6.9 Diagram



Figure 6.10 Photograph of seal around pipe.

6.3.3 Locations of tie in welds

There are two types of tie in weld:

Type 1 is the interface between floor geomembrane and slide slope geomembrane. The location of this weld must be a minimum of 1 metre across the level floor area from the toe of the slope prior to undertaking the seam weld. Careful consideration must be taken as to expansion and contraction of the geomembrane so not to cause ‘trampolining’ of the membrane or a ridge/wrinkle at the toe of the slope.

Type 2 is where welding to an existing membrane is undertaken. This weld should also be located a minimum of 1 metre from a slope toe or slope crest and within a level area. This type of weld is generally one of the most problematic and requires detailed consideration and planning. The location of these weld types are generally within the most hi-risk area of containment works and require further discussion with the design or CQA consultant.

Tie in welds to previous installations
When new membrane material is to be welded to an existing membrane (installed during previous membrane installation work) It is good practice whenever possible to join the two fmls together using wedge welding, as this generally achieves a stronger weld to extrusion welding and is often more efficient in time taken.

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Existing material will often be from a different production source to the new membrabne material to be joined meaning a mismatch of melt flow indexes. An assessment of the welding parameters will need to be conducted to ensure a good weld can be made and this will involve testing specimens taken from a pre-start test weld. These should be carried out in the tie-in site location using offcuts of the old and new geomembrane, replicating the proposed tie-in materials.

When, due to site circumstances or design an extrusion weld is required, a number of pre-start test welds should be made. With, extrusion welding 3 material compatibilities need to be taken into consideration (the 2 membranes and the extrudate or welding rod). Attention should be given to the fact that the optimum weld temperature of the two membranes needs to conform to each material and that of the extrudate. This is important as to ensure that the best possible weld strengths are achieved. In some circumstances a third source of extrudate material may be required which matches (as close as possible) the melt flow index of both geomembrane materials. Additional guidance can be sought from the material supplier in order to accomplish a satisfactory weld test result to meet site specification.

6.4 Reporting records during installation

Information should be referenced on the surface of site materials being installed using a bright permanent marker. The following should be considered:

- ***On deployment of a panel:*** the panel number, roll number and panel length should be added.
- ***On seaming:*** seam reference, technician, machine ID number, temperature setting, speed, start and finish time, seam length
- ***Seam testing APT results:*** start and finish time, start and finish pressure (CQA sign off).
- ***Patch repair:*** repair ref number, technician, machine id, temp settings (both melt and pre-heat), date and time, test results (signed off by CQA)

This information should be maintained and logged in the site report and used as a quick reference that all welding has been tested sufficiently.

7 Testing Welds and Joints

There are five main methods for testing welds and joints,
namely visual inspection, peel and shear test, spark test, pressure test and vacuum box.

The fundamental mechanism of joining polymer geomembranes sheets is to temporarily reorganise the polymer structure of the two surfaces in a controlled manner (ie melt or soften). After the application of pressure and the passage of a certain amount of time together with the polymer reorganisation by heating the result should be that the two sheets of geomembrane are bonded together homogeneously. This reorganisation results from an input of energy that originates from either chemical or thermal processes. These processes may involve the addition of extra polymer in the bonded area as in extrusion welding.

Ideally, seaming two geomembrane sheets would result in no net loss of tensile strength across the two sheets and the joined sheets would perform as one single geomembrane sheet. However, due to stress concentrations resulting from the seam geometry current seaming techniques may result in minor tensile strength loss compared to the parent geomembrane sheet. The characteristics of the seamed area are a function of the type of geomembrane and the seaming technique used. These factors, such as residual strength, geomembrane, and seaming type, should be recognised by the designer when applying the appropriate design factors of safety for the overall geomembrane function and safety performance. It is important to note that the welded seam can be the location of the lowest tensile strength of a geomembrane liner. Designers and inspectors should be aware of the importance of seeking only the highest quality of geomembrane seams.

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7.1 Destructive testing

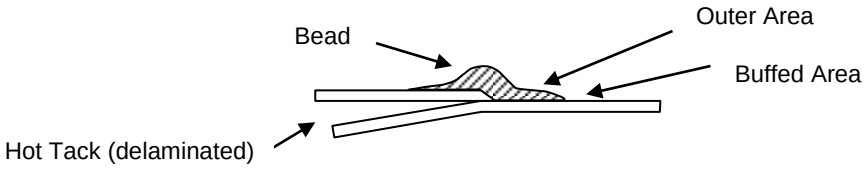
The peel test and the shear test are the only two destructive test methods used.

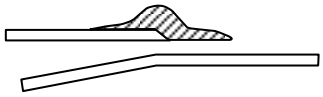
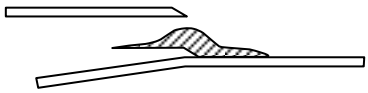
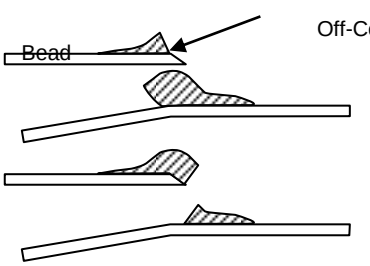
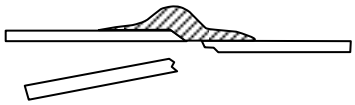
7.1.1 Peel test

The destructive testing of the tabs, which have been taken from a weld seam, should be tested in shear and peel modes as soon as possible after the seam has been completed. This is generally done at the site using a field *tensiometer* that has been calibrated and certified by an independent laboratory. Peel testing involves peeling the top sheet back against the overlapped edge of the bottom sheet in order to observe how separation occurs. The peel test indicates whether or not the sheets are continuously and homogeneously connected through the seam. Shear testing on the other hand applies a tensile stress from the top sheet through the weld and into the bottom sheet.

If the welding parameters have not been adhered to during the seaming process then it will become evident during the peel test, which is a very aggressive test of a seam, if there is a problem and what the problem is. For example, if the temperature of the extrudate in an extrusion weld was too high or if the speed was too slow then you are likely to see burn through on the underside of the sample. In the case of a hot air sample if the temperature of the wedge was too hot in relation to the speed then the area of the liner beside the weld is likely to be brittle and will in fact break at a low value. A table of typical failure modes is shown below in Figure 7.1.

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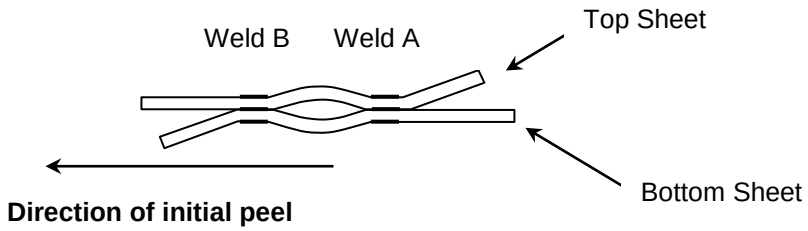


Types of Breaks	Locus-of-Break Code	Break Description	Classification[a]
	AD1	Failure in adhesion. Specimens may also delaminate under the bead and break through the thin extruded material in the outer area.	Non-FTB
	AD2	Failure in adhesion.	Non-FTB
	AD-WLD	Break through in the fillet. Breaks through the fillet range from breaks starting at the edge of the top sheet to breaks through the fillet after some adhesion failure between the fillet and the bottom sheet.	Non- FTB[b]
	SE1	Break at seam edge in the bottom sheet. Specimens may break anywhere from the brad/outer area edge to the outer area/buffed area edge. (Applicable to shear only).	FTB
	SE2	Break at seam edge in the top sheet. Specimens may break anywhere from bead/outer area edge to the outer area/buffed area edge.	FTB
	SE3	Break at seam edge in the bottom sheet. (Applicable to peel only).	FTB
	BRK1	Break in the bottom sheeting. A “B” in parentheses following the code means the specimen broke in the buffed area. (Applicable to shear only)	FTB
	BRK2	Break in the top sheeting. A “B” in the parentheses following the code means the specimen broke in the buffed area.	FTB
	AD-BRK	Break in the bottom sheeting after some adhesion failure between the fillet and the bottom sheet. (Applicable to peel only)	FTB
	HT	Break at the edge of the hot tack for specimens that could not be delaminated in the hot tack.	No Test

[a]FTB = Film – Tear Bond
[b]Acceptance of AD-WLD breaks may depend on whether test values meet a minimum specification value and not on classification as a FTB or non-FTB break.

Figure 7.1 Locus-of-break codes for fillet-extrusion weld seams in semi crystalline FML's tested for seam strength in shear and peel modes.

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Types of Break	Locus-of-Break Code	Break Description	Classification[a]
	AD	Adhesion failure.	Non-FTB
	BRK	Break in sheeting. Break can be either top or bottom sheet.	FTB
	SE1	Break at outer edge of seam. Break can be in either top or bottom.	FTB
	SE2	Break at inner edge of seam through both sheets.	FTB
	AD-BRK	Break in first seam after some adhesion failure. Break can be in either the top or bottom sheet.	FTB

Figure 7.2 Locus-of-break codes for dual hot-wedge seams in semi-crystalline FML's tested for seam strength in shear and peel modes. In cases where the Weld A fails in adhesion in a peel test, it is recommended that the test be stopped, that the specimen be replaced in the testing machine, and that Weld B be tested by peeling in the direction opposite to that used to Weld A.

The peel and shear test are the only destructive testing method used on geomembranes, all other tests are non-destructive. Destructive testing of seams is important because it provides direct evaluation of seam strength and bonding efficiency, which indicates seam durability. Destructive seam tests will be performed at randomly selected locations. The clients' representative or C.Q.A. Engineer will select locations where destructive samples will be cut. The destructive sample is usually 1.5m long by 0.5m wide and it will be cut into three sections. One section to be tested by the installer, one section to be sent to an off site laboratory if required, and the third section to be kept in archive storage by the client. Standard procedure is for the installer to cut ten tabs from his portion of the sample and to test each alternative one in peel and shear. Depending on the sample passing criteria for the project, which can vary, at least three of the tabs tested in both shear and peel must pass the minimum requirements for that particular project. Should this criteria not be met for any particular destructive sample then it will be necessary to take another sample within two metres either side of the failed sample. Both of these samples will have to pass the minimum pass requirement for the project. Information on weld specifications will be dealt with elsewhere in this document.

7.1.2 Shear test

Shear testing of tab samples cut from a welded seam can be used for testing the integrity of both extrusion and fusion welds. This test is always used in association with peel testing. For both types of weld the test represents the forces imposed on the seam resulting from possible tensile stresses in the liner perpendicular to the line of the seam.

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For a fusion weld, the welded bond between the joined liners is sheared; the test is designed to show that this bond is stronger than the yield strength of the parent sheet. For an extrusion weld the purpose of the test is also to shear the bond between the joined sheets. In addition, the test will reveal if the height of the weld crown is greater than the sheet thickness, if not then failure will occur in the extruded weld itself

7.1.3 Acceptance Criteria

Minimum Tensionmeter Values						
HDPE	**Newtons/25.4mm wide samples (one inch)**					
Thickness	0.5mm	0.75mm	1.0mm	1.5mm	2.0mm	2.5mm
Shear Strength	178	267	356	534	712	890
Peel Strength (Fusion)	133	200	267	400	534	667
Peel Strength (extrusion)	116	174	231	347	463	578
LLDPE	**Newtons/25.4mm wide sample (one inch)**					
Thickness	0.5mm	0.75mm	1.0mm	1.5mm	2.0mm	2.5mm
Shear Strength	133	200	267	400	534	667
Peel Strength (Fusion)	116	174	236	356	472	587
Peel Strength (extrusion)	98	147	200	303	405	507
Minimum Tensionmeter Values						
HDPE	**Lbs/inch wide samples**					
Thickness	0.5mm	0.75mm	1.0mm	1.5mm	2.0mm	2.5mm
Shear Strength	40	60	80	120	160	200
Peel Strength (Fusion)	30	45	60	90	120	150
Peel Strength (extrusion)	26	39	52	78	104	130
LLDPE	**Lbs/inch wide samples**					
Thickness	0.5mm	0.75mm	1.0mm	1.5mm	2.0mm	2.5mm
Shear Strength	30	45	60	90	120	150
Peel Strength (Fusion)	26	39	53	80	106	132
Peel Strength (extrusion)	22	33	45	68	91	114
Conversion N/mm² to lbs/inch width (multiply by)	2.855	4.282	5.709	8.564	11.418	14.273
1 kg = 2.205lb	1 Mpa = 1 N/mm²					
1 inch = 25.4mm	1N/mm² = 144.86 psi					

Figure 7.3 An example of the parameters and the expected values for the various thicknesses of materials.

Outlined in the table is an example of the parameters and the expected values for the various thicknesses of materials which destructive samples should reach under test in the laboratory or on a calibrated site tensiometer. The standard in this case is ASTM D4437. If a welding machine is calibrated properly and operated properly in the right conditions then the above measurements can be achieved. If the measurements for peel and shear on the tensiometer are less than those listed above then the sample would be considered a failure and the type of failure will usually be one of those listed above in Figure 7.1 and Figure 7.2, and the reason for the failure can then be established.

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The increased use of geomembranes as barrier materials to restrict liquid migration from one location to another in soil and rock, and the large number of seam methods and types used in joining these geomembranes has created a need for standard tests by which the various seams can be compared and the quality of the seams systems can be evaluated.

7.2 Non-Destructive testing

7.2.1 Visual inspection

7.2.1.1 Extrusion welding

Visual inspection of the extrudate bead should be made particularly for straight-line alignment, height and uniformity of surface texture. There should be no bubble or poc marks in the extrudate. Such surface details on the extrudate indicate the presents of air, water or dust within the extrudate rod or granulate. Sand marks should only be visible for 6 mm beyond the extrudate. They should be extremely faint and never appear as heavy gouge marks. The seam must be checked for uniformity of width and surface continuity, any area of the geomembrane where puncture holes are observed must be patched with a piece of geomembrane 300mm dia minimum.

7.2.1.2 Wedge welding

For HDPE and LDPE a slight amount of “squeeze out” is a good indicator that the proper temperatures were achieved, as shown in Figure 7.4. It signifies a proper seam in that some of the melted polymer was latterly squeezed out of the seam zone. If an excessive amount of hot melt is being squeezed out it is an indication of either too much heat, too much pressure, or too slow a seaming speed.

Nip/drive roller marks should show on the surface when using knurled rollers. Their depth should be visually observable, but care should be taken to ensure that the drive rollers do not create a rut ie the indentation should be barely capable of being felt.

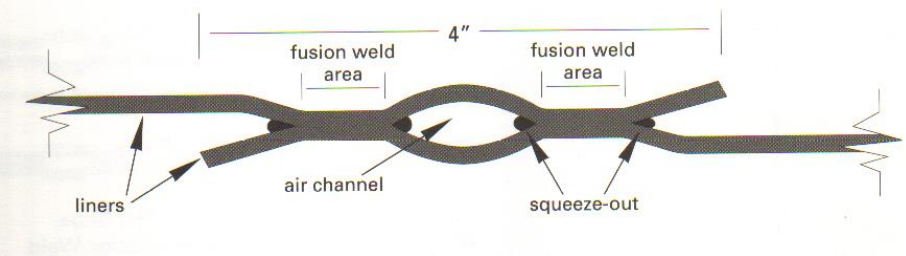


Figure 7.4 Double track fusion weld.

The seam must be checked visually for uniformity of width and surface continuity. Any area of the geomembrane where puncture holes are observed must be patched with a piece of material extending at least 15cm beyond the affected areas.

7.2.1.3 Hot air welding

Similar to the hot wedge weld, a slight amount of squeeze out or flashing is a good indicator that the proper temperatures were achieved. It signifies a proper seam in that some of the melted polymer was latterly squeezed out of the seam zone. If an excessive amount of hot melt is being squeezed out it is an indication of too much heat, too much pressure, or too slow a seaming rate. For VLDPE and LLDPE liners of 1mm thickness or less a long, low wavelength pattern in the direction of the seam along its top surface is indicative of a proper weld. If the wave peaks become too close together, the machine speed should be increased until a satisfactory pattern is present. The absence of this wavelength pattern indicates that the speed should be decreased. Nip/drive roller marks may show on the surface when using knurled rollers. Their depth should be visually observable, but care should be taken to ensure that the nip/drive rollers do not create a rut i.e. the indentation should be barely capable of being felt.

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7.2.2 Spark test

This test is used for non-destructive testing of extrusion welds only. The equipment used is a continuous coil high frequency spark tester with adjustable voltage in the range 15 to 30 kilo volts. Since plastic is an insulating material it is necessary to use a conductive material for this test and this material is usually a copper wire which is inserted in the seam after tacking and sanding and before extrusion. As a general rule the spark test equipment shall be adjusted to provide a voltage of approximately 10 kilo volts per mm of the geomembrane thickness being tested. When carrying out the spark test the spark test probe is passed slowly, and at a suitable height along either side and along the centre of the bead of extrudate. Any voids in the extruded bead establish electrical continuity and allow a spark to pass between the copper wire and the probe. It is important to note that the spark test is not an indication of the strength of the weld but is a very accurate method for pinpointing defects in the continuity of the extruded bead.

Spark testing on land fill sites is covered in Health and Safety DSEAR regulations 2002. The best method of removing any risk is to utilize a vacuum test.

7.2.3 Air pressure test

The air pressure test is unique to the double track fusion method of wedge welding, by the hot air wedge or heated wedge. A double track fusion weld is composed of a primary seam and a secondary track that creates an unwelded channel. The presence of an unwelded channel allows both fusion seams to be tested by inflating the sealed channel with air to a predetermined pressure and observing the stability of the pressurised channel over time.

The equipment necessary for air pressure testing consists of:

- An airpump capable of generating and sustaining a pressure between 1.7 and 2.1bar.
- A rubber hose with fittings and connections.
- A sharp hollow needle or other approved pressure feed device with a pressure gauge capable of reading and sustaining a pressure between 1.7 and 3.0bar.
- A clamping device.

The procedure for air pressure testing is as follows:

- Seal both ends of the seam to be tested.
- Insert the needle or other approved pressure feed device into the sealed channel created by the fusion weld. It will be necessary to heat the liner with a hot air gun or other heating device prior to inserting the needle. This process enables the needle to be inserted easily and also helps to create a seal between the liner and the needle as the plastic cools.
- Inflate the test channels to a pressure given in the table below using the airpump and maintain the pressure within the range listed. Close the valve and observe and record the initial pressure after approximately two minutes.
- Record the results and add to the surface of the membrane (Figure 7.5).

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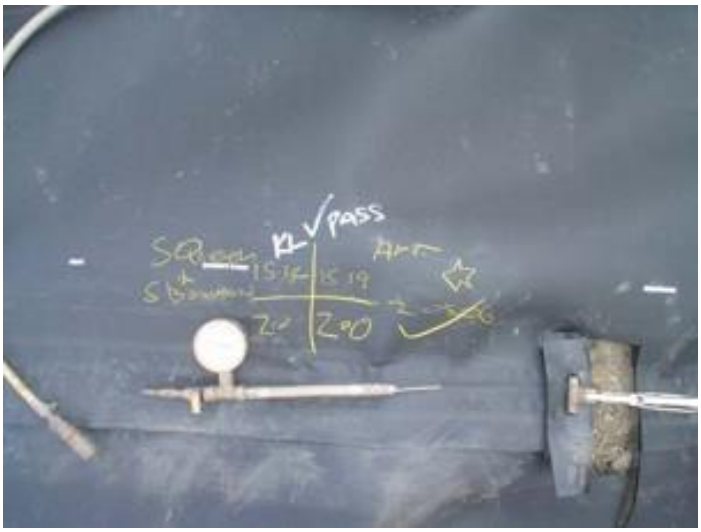


Figure 7.5 Air pressure test results clearly visible on membrane.

Initial Pressure Schedule

Material thickness (mm)	Min. pressure (bar)	Max. pressure (bar)
1.0	1.63	2.04
1.5	1.84	2.38
2.0	2.04	2.38
2.5	2.04	2.38

Initial Pressure settings are read after a 2-minute 'relaxing period'. The purpose of this relaxing period is to permit the air pressure and temperature to stabilise.

- Observe and record the air pressure five minutes after the initial pressure setting is recorded. If loss of pressure exceeds 10% of the initial pressure or if the pressure does not stabilise there is a leak which will be necessary to locate and repair.

At the conclusion of all successful air pressure testing the end of the air channel opposite the pressure gauge should be cut. A decrease in gauge pressure should be immediately obvious, if it is not, then it can be assumed that the air channel is blocked and the test should be repeated from the point of blockage. As a general rule of thumb, if the point of blockage cannot be easily found by means of visual inspection then the air channel should be cut in the middle of the seam and each half treated as a separate test.

- Remove the needle or other approved pressure feed device and seal the resulting hole by extrusion welding.

In the event of an air pressure test failing the following procedure should be followed:

- Check seam end seals and retest the seams.
- If the seam will not maintain the specified pressure, the seam should be visually inspected in order to identify the flaw. If the flaw is not obvious then the fastest method of narrowing down the affected area is to go to the centre of the seam and carry out the air pressure test in two halves. Once the section of the seam with the defect has been identified, this process can be repeated again in order to locate the fault. If the seam is relatively short, for example, 20m, it may be faster to cut off the tab left by the overlap of the wedge weld and to extrude the seam and then carry out a vacuum box test.

7.2.4 Vacuum box test

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The Vacuum Box test is a method used to non-destructively test extrusion welds and fusion welds when the geometry of the weld makes air pressure testing impossible or impracticable or when spark testing of an extrusion weld is unable to be undertaken, due to DSEAR regulations.

The equipment for vacuum testing consists of:

- A vacuum box assembly, consisting of a ridged housing, a transparent viewing window, a soft neoprene gasket attached to the bottom of the ridged housing to form a seal against the liner, a port hole or valve assembly and the vacuum gauge.
- A vacuum pump assembly equipped with a pressure pump and a pipe connection.
- A rubber pressure/vacuum hose with fitting and connections.
- A soapy solution and a means of applying it to the line.

The procedure for vacuum testing:

- Trim excess overlap material from the seam in the case of a fusion weld.
- Turn on the vacuum pump and set it to produce approximately 0.35bar of vacuum.
- Apply a generous amount of a strong soapy solution and water to the area to be tested. This helps to create a vacuum.
- Place the vacuum box over the area to be tested and apply sufficient downward pressure to form a seal between the vacuum box and the liner.
- Close the bleed valve and open the vacuum valve.
- Apply a minimum of 0.35bar to the area as indicated by the gauge on the vacuum box.
- Ensure that a leak tight seal is created.
- For a period of approximately 10-15 seconds examine the geomembrane through the viewing window for the presence of air bubbles. If no air bubbles appear, the test is successful and the vacuum box can be removed to the next section of the seam, and the test repeated. It is important that an overlap of a minimum of 75mm is maintained every time the vacuum box is moved along the seam.

In the event of air bubbles appearing, the area should be marked and repaired by means of an extrusion bead or a patch depending on the nature and extent of the damage. The repaired area should be re-tested. Particular attention should be exercised when vacuum testing “T” seams or patch intersections with seams as these areas are at most risk of having a defect and are also the most difficult to test by means of a vacuum box as it maybe difficult to achieve a seal between the vacuum box and the liner.

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8 Weld Quality

8.1 Types of imperfection

The first step in identifying weld imperfections is to inspect the weld visually. Given the nature of the different types if welding there will obviously be different imperfections or faults in extrusion seams and fusion seams.

When visually inspecting an extrusion seam special attention should be paid to the following:

- Alignment of the extrusion bead (ribbon).
- Consistency of the surface texture of the bead (ribbon).
- There should be no bubbles or pop marks in the extrudate.
- Sanding marks should only be visible for 6mm beyond the extrudate. The sanding marks should be faint and never appear as heavy gouge marks.

In the case of fusion seams a visual inspection should take account of the following:

- The nip/drive roller marks may show on the surface of the liner when using knurled rollers. Their depth should be examined to ensure that the rollers have not created a rut i.e. the indentation should be barely capable of being felt.
- The seam should be check for uniformity of width and surface continuity. In the case of dual track seam both seams should be clearly identifiable separated by the air channel.
- There should be enough of a flap outside of the weld to allow for peel testing of the weld during a destructive test.

The same procedure as outlined for the fusion weld would apply to the hot air fusion weld.

8.2 Origins of imperfections

The origin of weld imperfections includes the following:

- Welding in unsuitable conditions i.e. during rain, excessive wind or on poor subgrade.
- A badly adjusted welding machine.
- Poor operation of the automated or hand held machine.
- Wet or damp granulate or wire rod in the case of extrusion welding.

Either one or a combination of the above list will lead to poor quality seams and under scrutiny by means of a tensile test the fault will become apparent as shown in Figures 7.1 and 7.2.

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9 Site Working

9.1 Cleaning procedures

Before any welding can begin it is necessary that the liner to be welded is clean, dry and free of any dust or dirt particles.

If the liner is wet when starting work in the morning due to over night rain or dew then a squeegee should be used to push off surface water from the area to be welded. After the surface water has been removed, the area to be welded will need to be clean and dried using a cotton cloth. In a case where the edge of a panel of liner was laying on wet sub-grade over night or in some cases for several days then it may be necessary to remove mud which is stuck to the underside of the liner by using a scraper of some sort. Often a piece of waste liner material can be used to make a scraper, which will remove the dirt but will not damage the liner. After the mud has been removed the edge of the liner will need to be cleaned and dried with a dry cloth prior to seaming.

In the case of an extrusion weld, the liner will need to be clean and dried before tacking can take place. The same procedure as above, applies if the liner has being laying on wet sub-grade. Sometimes it maybe necessary to sand the area of liner to be welded prior to tacking, this is done using a hand held sander as described in the section on extrusion weld.

In dry, dusty conditions dust will be removed by wiping with a cloth, in the case of an extrusion weld and a wedge weld.

Where there is a large quantity of surface water present in the area of the seam it may be necessary to use a wet-vac to suck up and remove surface water. In the case of torrential rain and consequently a site being flooded, it will be necessary to use a pump to remove the surface water firstly before any of the other cleaning methods can be used.

9.2 Weather protection

As a general rule neither welding, nor placing of geomembrane will take place during any precipitation or in the presence of excess moisture, blowing dust or high winds. In addition neither placement nor welding of geomembranes should take place in areas of standing water.

The two main elements, which cause disruption to the installation of geomembranes, are water, in the form of rain or standing water, and wind.

The only protection against rain, which is effective, is to utilise a tent or canopy when carrying out repairs or localised welding. But in general, rain will bring to a halt all welding procedures.

Standing water is a problem, in that it is not acceptable to deploy membrane in areas of standing water. Where there is standing water on the surface of geomembrane it is possible to remove the standing water by means of a pump, wet-vac, or by a hand held squeegee. Dry cloths can then be used to dry the seam prior to welding.

Wind can affect geomembrane installation in two ways. The first is by causing problems with deploying liner panels as the liner reacts like a kite once the wind gets under it and is impossible to control. Therefore, liner deployment can generally only take place during calm conditions. It is crucial that exposed liner panels are ballasted immediately after deployment by means of sandbags or tyres, particularly in the area of the exposed edge. On embankments or slopes a system known as a Trout-line is used to ballast liner panels. The trout-line is a line of sandbags equal distance apart (usually one metre) connected by a

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rope, which is secured in an anchor trench at the top of the slope by means of an anchor pin.

The wind can also be a problem for extrusion welding and wedge welding as it has the effect of blowing away the preheat in the case of extrusion welding, and cooling the wedge in the case of the wedge welding. In the case of hot air wedge welding strong wind has the effect of decreasing the temperature of the hot air flow. The only means of protecting against the effects of the wind, in these situations, is by means of using a shield, which usually takes the form of a section of liner held in place by a technician directly in the path of the wind, just in front of the welding device. The purpose of the shield is to divert the wind away from the hot air blower or the heated wedge. A tent or canopy will also offer a limited protection against the wind.

The sun can also cause problems during installation of geomembrane in the form of wrinkles in the geomembrane, which can be a problem, particularly for wedge welding. The sun causes the top liner to expand more than the bottom liner which has the effect of creating surplus material on top and this can sometimes be a problem when feeding the liner through the wedge welder drive rollers. The effect can be that the wedge welder is stopped in the seam because of too much overlap or because a wrinkle has been created which is too big to feed through the machine. The effect in both situations is that the wedge will burn through the liner causing a repair. It is important that the operator of the wedge is aware of the ambient temperature and the effects that it is having on the seam he is welding, and that he keeps an eye on the overlap ahead of him at all times to ensure that it is within the acceptable overlap allowed. If the overlap is too big then the operator or an assistant needs to trim the bottom panel just in front of the wedge welder.

In the case of extrusion welding in hot temperatures, it is important that the operator of the extrusion machine feeds or walks the wrinkles gradually either towards or away from him so that he does not cause a build up of surplus material which can result in the seam opening or in a burn through effect.

Wherever possible perimeter connections between embankment and flat areas should be carried out at the coolest time of the day or night, when the liner is fully contracted. If this procedure is followed it will minimise the risk of causing a trampolining effect at this critical point.

9.3 Shipping, storage and handling and deployment of geomembranes

9.3.1 Shipping

Shipping or transporting of geomembrane rolls are generally shipped in one of three ways, either by shipment in a closed container, an open top container or on a flat bed trailer.

9.3.1.1 Closed container

In the case of a closed container the liner is loaded at the factory by means of a “stinger” or “carpet pole”. This is a pole like attachment to a forklift. The pole can be inserted into the core of the roll and then lifted and placed into the container. Each roll has two slings attached to assist with ease of handle on site. When the closed container arrives on site or in a storage yard it is necessary to have a stringer or carpet pole attachment which can be attached to an excavator or other similar piece of site equipment in order to unload the rolls in the same manner in which they were loaded. It is not always possible or practical to have a “carpet pole” on site. The usual method of off loading is by using a standard excavator.

9.3.1.2 Open top container

In the case of the open top container, the rolls of geomembrane are placed in the container by using a gantry crane which lifts the rolls by means of two lifting slings or straps, which are positioned along the length of the roll. When the open top container arrives on site the rolls can be taken out of the container by using an excavator to lift the rolls free of the

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container, by means of the straps or slings attached to the bucket of the machine by means of a lifting shackle.

9.3.1.3 Flat bed trailer

The flat bed trailer is used when the rolls of geomembrane are being transported solely by road where as the other two methods outlined above involve transport by a combination of ship and rail or road. The rolls are loaded onto the trailer at the factory by a gantry crane, lifting the rolls by means of the slings or straps. When the truck reaches its destination the rolls can be lifted from the trailer by means of a forklift, an excavator or another suitable piece of equipment. The rolls can be stacked on the trailer in a triangular configuration to utilise the maximum weight allowable. This takes the form of three rolls side by side across the width of the trailer, two rolls side by side on top of these and a single roll on top.

9.3.1.4 Storage

Rolls of geomembrane should be placed on a smooth, dry surface, free of sharp stones and stacked no more than two rolls high. The bottom rolls need to be supported by chocs or timbers to prevent them rolling, and each roll should have two slings attached so that they can be easily lifted and moved when required. Geomembrane rolls are UV stabilised by means of the addition of carbon black during manufacturing, and require no special protection from moisture or sunlight.

9.3.2 Handling and deployment

Geomembrane rolls should be handled using the attached straps or slings or if adequately sized equipment is available, by means of a “stinger” inserted through the core. In the manufacturing plant, rolls will usually be transported from the factory floor to the storage area by means of a gantry crane or by a forklift with a stinger attachment. In a site situation the rolls of geomembrane will be carried using an excavator which lifts the rolls by means the straps, or by utilising a stinger attachment as described above.

The main deployment method currently used for the deployment of geomembranes is by means of the spreader beam. The spreader beam consists of a main carrier beam, which extends approximately 1.5m either side of the roll being carried. Attached to either end of the beam are lifting ends which slide along the beam and have a section which fits into the core of the roll. These ends can then be locked in position before the beam is lifted by means of chains, attached to the lifting eyes of the beam and to the bucket of the excavator.

Once the lifting beam with the roll attached is hoisted clear of the ground by the excavator, it is then possible to pull the liner from the roll. The roll will spin on the beam because of the use of bearings fitted to the beam ends, which are inserted in the core of the roll. In a situation where the liner is being deployed from the top of a slope, the excavator will be positioned near the crest area, and will position the roll in order that the deployment crew can pull the liner by means of grips or clamps attached along the width of the free end of the roll. In a situation where the liner is being deployed on a flat area, the membrane will be deployed by means of the excavator lifting a roll just above the sub-grade level and then proceeding to track backwards. For the first 20m or so, it will be necessary to anchor the free end of the roll by means of ballasting, but after 20m or so, the weight of the material will be enough to keep the panel in position, as long as there is no sudden jerk by the excavator operator during deployment. Once the panel has been deployed to its full length, the liner is cut from the remaining material on the roll by means of a hook knife, and the overlap is then set correctly by tugging the liner into position by using vice-grips or clamps.

9.4 Subgrade acceptance

The essential requirements for the installation of the geomembrane are a smooth, dry and clean working surface.

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Particular attention should be paid on the following:

a) Grain size and angularity: The subgrade (ie the material immediately beneath the membrane) should be free of any objects, which may puncture the membrane. For HDPE the maximum particle size (in a material such as boulder clay) in contact with the geomembrane is 20mm. Any stone, which protrudes above the level of the surface of the subgrade, should be stone picked and any indentation remaining should be filled and compacted with suitable material.

b) Chemical composition: The subgrade should be free of any form of contamination that may chemically affect the selected geomembrane material.

c) Smooth and firm: The surface onto which the geomembrane is to be laid should be as flat as possible. Undulations can require cutting and welding of the geomembrane, since the joints can be weak points in the liner their number should be minimised.

Firm in this context means that indentation cannot easily be made in the surface. For clays the shear strength should be >50kN/m^2. For other materials such as sand the material should be >90% of its maximum dry density to ensure no movement will occur during or after placement of waste.

Smooth means that there are no sharp angles in the subgrade, which exceed ±10mm under a 1000mm lath (eg rutting) and no large rounded irregularity should exceed ±50mm under a 3000mm lath.

Subgrade acceptance forms should be filled out and signed by all parties involved (installers, lead technicians, CQA engineers, client representatives and earth works contractors) for each deployment period. The panel numbers should be clearly referenced and visual checks of the surface should be made prior to the deployment of each fml panel.

9.4.1 Bentonite enhanced sand (BES) as a subgrade

When carrying out any welding procedure on BES as a subgrade, it is important that particular attention is given to the cleaning process in preparation for welding. Experience has shown that when bentonite attaches itself to the liner, particularly in wet conditions, it is very difficult to clean the liner and when due care and attention is not shown the number of weld failures increases.

9.4.2 Geosynthetic clay liner (GCL)

Similar to BES, GCLs also present welding problems when placed directly underneath the membrane, as the bentonite powder which is placed in the overlaps of GCL panels is often scattered by the wind or water, and causes cleaning problems in preparation for welding. The personnel placing the bentonite powder should take care not to place excess amounts of powder in the joints, or on the liner.

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10 Related Geosynthetic Materials

11 A wide range of associated products are often incorporated within a geocomposite lining installation . These associated products form an important part of the containment solution and failures can occur if installation is not carried out with the same standard of skill and attention to detail as the primary containment works.

11.1 Geosynthetic clay liners (GCLS)

GCLs are factory manufactured hydraulic barriers consisting of a layer of bentonite or other very low permeability material supported by geotextiles and or geomembranes, mechanically held together by needling, stitching, or chemical adhesives, (Koerner, 1998, Designing with Geosynthetics)

Deployment handling and storage

GCL must be stored in a manner as to prevent any water absorption. The stock rolls of material should be placed on a built up platform, off the ground. A rain proof sheet or tarpaulin should be securely placed over the material (the wrapping supplied on the rolls is only light duty and will not prevent rain damage). The lower rolls of material must be secured to prevent rolling and they should not be stacked more than 2m high.

Deployment is usually undertaken by utilising a spreader beam and 360 excavator. The orientation of side deployment will allow the excavator to track to the side of the panel deployment area (the track markings are then removed by re-rolling of the subgrade prior to the placement of the next panel). Great care must be given to maintaining the minimum overlap along the sides of the panel. Most products have marker lines along the edge, however if this is not the case, then periodic marks should by drawn on, prior to deployment.

Other methods of deployment can be used, although note that vehicle tracking directly in front of the GCL placement, on the prepared subgrade, can cause damage/disturbance to the subgrade surface and should be avoided.

The material must be laid in a uniform manner, flat to the subgrade surface and free of wrinkles. When laying the material onto a surface, which is not uniformly flat over a large area it may be required to overlay a joint to ensure the minimum lap, is maintained along its length.

Orientation of the joint is important when deploying on slopes and inclines. Panels must be laid where joints are perpendicular to the slope. When working around corners, the panels should be cut at angle, to ensure the correct finished orientation of the joint

Consideration should always be given when traversing panels across small inclines within the tolerances of the design specification.

During deployment continual monitoring of weather conditions should be maintained and any likelihood of rain noted. It is of paramount importance that the GCL does not absorb moisture prior to the next impermeable layer being sealed over it. it is recognised as bad practice to leave the work area with any GCL left uncovered

At the end of any daily shift, the leading edge of the GCL should be folded back to the cover layer and encased in plastic sheeting to protect against the GCL becoming hydrated.

Some GCL products are supplied with additional bentonite pre-placed along the side edge, within the overlap area, and require no additional bentonite powder to be placed. - this is only the case along the sides of the panels. In situations where the panel has been trimmed (to allow reorientation of the seam) the overlap joint will require additional bentonite power to

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be placed within the joint. The design documents or the CQA plan will state the amount of powder measured in grams per running metre. The powder is generally supplied in paper bags which will need to be stored under cover to prevent water absorption. The operative should tip the bag and move it along the jointed area leaving a continuous line of powder (ensuring the minimum grams per running metre is achieved). A one metre length of dust should be marked out, then using a soft brush and dust pan, the additional powder collected and weighed and results recorded.

Patch Repairs
Wherever damage has occurred to the GCL (mechanical or water absorption) over patching will be required. Any patch should extend a minimum of 300mm beyond the extent of the damaged area. The jointing of the patch should be powdered using the initial procedures and guidelines.

11.2 Geotextiles

A permeable geosynthetic comprised solely of textiles (ASTM D4439).

Geotextiles used in conjunction with a geomembrane are primarily for protection of geomembrane. These materials are usually made of needle punched staple fibre. The geotextile must contain a UV inhibitor in order to ensure that it will not degrade in sunlight. The UV inhibitor can either be carbon black or a chemical inhibitor. The weight of the geotextile to be used to protect the geomembrane will be determined by the type of materials in direct contact with it. For example, cover soils or drainage medium and the weight loading on the system .

A number of labourers will usually undertake deployment of these products (as the material is relatively light). it is worth considering the placement of the material above a geomembrane lining system, as lining works proceed across the site with access across the sub-grade prior to geomembrane placement/deployment. The geotextile requires flat deployment with no wrinkles and minimum lap maintained.

Jointing
A number of jointing methods are available. These will be specified in the design documents/drawings for the project or the CQA plan. if this is not the case then information should be sort from the material manufacturer.

Over lapping
This jointing method simply involves overlaying a panel of textile by a minimum width of typically 500mm to 1000 mm. Careful consideration of the direction of placement of cover materials should be taken and the joint lapped with the direction of travel so as not to disturb the overlap during subsequent operations. Repairs to damaged areas should be undertaken by over laying with a patch (the patch should extend beyond the damage by the same distance as the designed overlap). This method of site installation can be problematic as panels can easily move and become disturbed either due to wind or slipping during placement of cover soils.

Tack / heat bond
The textile will be overlapped by a minimum measurement (usually 150-200mm). Introduce a heat knife or hot air gun with suitable nozzle between the lap and a small amount of pressure, until the materials are joined together.

Care must be taken not to melt though the material which will result in localised damage and a decrease in its performance. Where any repairs are required a patch should be placed over the damaged area extending the distance as per the joint lap(150-200mm). This type of joint attains a more secure structure whilst retaining the panels in place and reduces the likelihood of the joint being spit during subsequent site operations (ie

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placement of cover soils or drainage medium). Laps should still be orientated, taking the direction of travel used in these operations into consideration. The other advantage of this jointing method is that the lapped area will be reduced, which reduces the volume of material used.

Sewing

A number of portable sewing machines (Figure 11.1) are available from various manufactures for use on-site. These machines are quite delicate and need to be operated by skilled and trained individuals. During operation, the process usually requires assistance from another person so that material lap and orientation is retained. The thread for joining needs to be approved to the project, taking into account its strength and resistance to any degradation. Two types of sewn joint configuration is shown in Figures 11.2 and 11.3.



Figure 11.1 Portable sewing machine

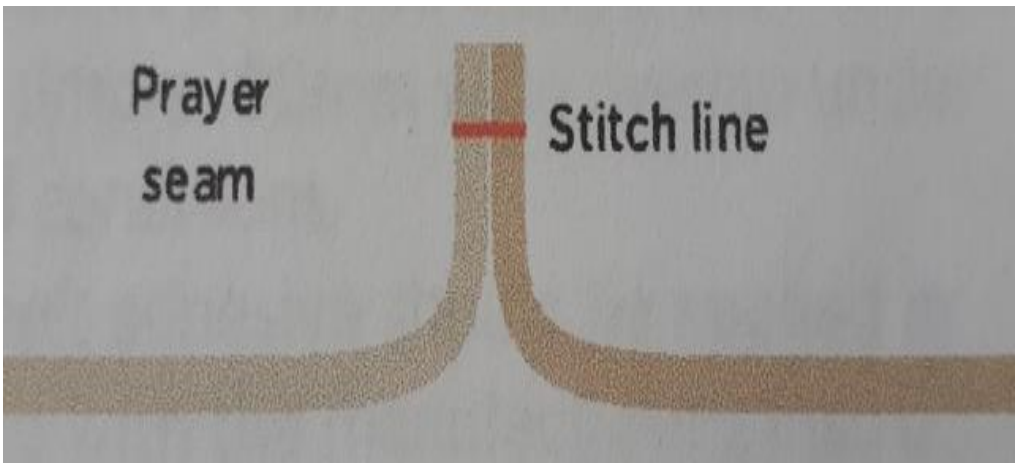


Figure 11.2 A sewn joint configuration

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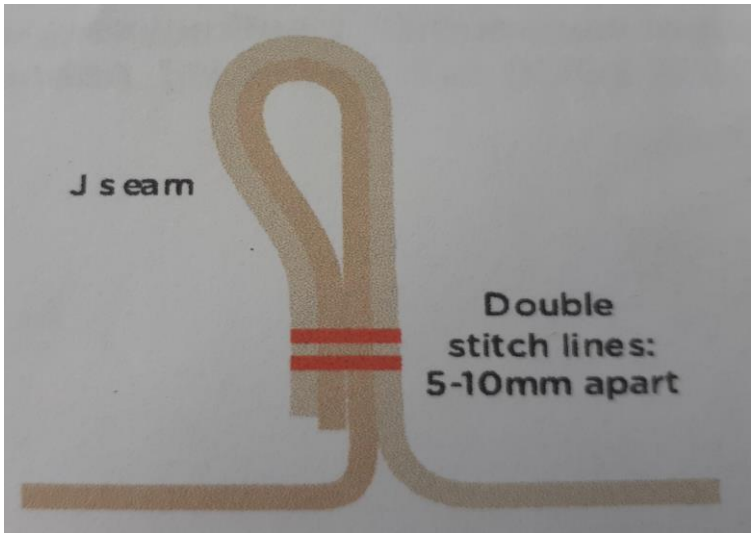


Figure 11.3 A sewn joint configuration

11.3 Geonet

Geonets are often laminated with geotextiles on one or both surfaces and are often referred to as geodrains (Koerner, 1998, Designing with Geosynthetics).

Geodrains are used in landfill aplications to replace or reduce the quantity of drainage stone required, but are usually as effective. Trials are currently being undertaken to investigate this and it is anticipated that in the future, their use may become common. Geodrains must be installed in accordance with the design documents and CQA plan, considering manufacturers recommendations.

Installation and deployment of Geonets is undertaken by manually rolling out the material across the required area, ensuring the minimum overlap (generally between 100-300mm) is maintained, dependent upon design docs/CQA plan. The Geonet must be laid flat to the surface without any wrinkles present. The overlap should then be maintained and securely fastened with cable ties, usually 300 to 500mm apart along the length of the joint.

11.4 Geocomposites

The basic philosophy behind geotextile (geocomposite) materials is to combine the best features of one or more materials, in such a way that specific problems are resolved in the optimal manner.

One of the most common geocomposites used is a geonet material or egg-box corrugated material with a textile on either one or both sides. The separation and filtration functions are provided by the geotextile and the drainage function is greatly improved due to the presence of the geonet.

Placed horizontally, the composites make excellent drains to moving water in a capillary zone where frost heave or salt migration is a problem. When the water enters the sandwich of materials it travels horizontally within the geonets and away from where the damage can occur. In landfill design, geocomposites such as these have also been used in intercepting and conveying leachate to collection areas and for conducting vapour or water beneath pond liners of various types.

Installation of these products should follow the above procedures. The drainage layer should be butt jointed with the textile over lapping and heat sealed to prevent the joint been disturbed (i.e. splitting during subsequent site operations).

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Types of geocomposite include:

- Geotextile – Geomembrane Composites.
- Geomembrane – Geogrid Composites.
- Geotextile – Geogrid Composites.
- Geotextile – Polymer Core Composites.

Once deployment and jointing of the geosynthetics has been completed, a large proportion of sites/projects require either cover soils or drainage medium to be placed on top. Great care must be given to this works as damage to the underlying geocomposites can occur, which in turn compromises the integrity of the whole containment system (shown in Figure 11.4).



Figure 11.4 Example of machine damage.



Figure 11.5 Example of stone damage between layers of geocomposites.

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It is common for cover materials to have a required specific depth of first layer ,on a contaminated land cap. The design may require a fine graded particle size within the first 300mm of cover and then 600mm of general sub soil, followed by 100mm of topsoil, suitable as a growing medium. This type of works requires careful planning and preparation, as wheeled equipment should never traffic over the containment geocomposites without a minimum cover of 1 metre. A typical example of cover material construction is given below:

- Engineered clay
- GCL bentomat
- 2mm HDPE membrane
- Protective geo textile
- 300mm drainage stone

On completion of the textile installation, access points over bund walls are identified. The edge of the ramp directly above the anchor trench should be formed to a minimum depth of 1 metre above the lining system on the bund crest. A 360-degree excavator of suitable size should be tracked up the ramp to the leading edge to deliver stone to the rear of the excavator tipping on the ramp. Using the excavator bucket to transfer the stone and place carefully to the toe of the bund at the furthest reach of the machine (great care must be taken not to disturb the Geosynthetic materials). Repeat this procedure filling from the furthest point back to the excavator. Following this, track the excavator forward on to the newly formed part of the haul road and repeat the exercise, always starting at the maximum reach and backfilling to the excavator. This method prevents small natural surpluses in the Geosynthetic containment system been pushed into a large surplus, which would form a bow wave affect and eventually material would fold over itself forming a crease, which would then incur stress cracks. In addition, if the material moved laterally, it would induce additional stress into the joints and could cause separation and a potential failure of the system.

The haul roads need to be constructed across the base area maintaining the 1 metre minimum depth at all times. This will allow the wheeled dumpers to transverse them whilst not damaging the Geosynthetics below. The haul roads should run parallel to each other and be spaced around 10 to 12 metres between edges.

Once the furthest side of the site has been reached the excavator can proceed working back towards the access point to spread the drainage material. The excavator can stand on the haul road, removing stone from the road and again placing it at a depth of 300mm from the furthest reach of the machine, back to the haul road, so as not to disturb the Geosynthetics or create a bow wave in the material.

Where necessary it is acceptable for the tracked excavator to transverse over the 300mm layer however this type of work should be kept to a minimum and great care must be given to not sprag the tracks, as this will introduce lateral movement in the drainage stone, which would disturb the Geosynthetics below.

Contaminated ground capping typical build up from bottom

- Suitably prepped sub soils.
- FML Geomembrane with geotextile protection or GCL bentonite product.
- 300mm fine grade soils.
- 600 mm general fill subsoils.
- 100mm suitable growing medium.

The sequence of forming haul roads across the area of capping using the screened fine grade material placed by a suitable sized excavator should be followed paying particular attention to maintaining a minimum depth of 1 metre. Once the first 300mm layer has been

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spread this should be sufficient to keep the Geosynthetics in place during placement of the next layer using trucks fitted with a blade. Careful monitoring of the depth, ensuring a minimum depth of 1 metre, should be undertaken, especially where any wheeled trafficking (dump trucks) are present. It is generally acceptable for the tracked blade/dozer to travel at 900mm although the pushing of excessive amounts of material should not occur as movement can be transferred down though the cover material into the surface of the Geosynthetics creating damage and displacement.

12 Appendix 1

12.1 Documentation

12.1.1 Geomembrane installation specification

Outlined below is a typical project specification for geomembrane liner material supply and installation, as it would appear in a project tender document. Table 11.1.

12.1.1.1 Geomembrane materials

The geomembrane shall consist of high density polyethylene (HDPE) unlaminated material, textured on both sides. The material should be produced from new resins and contain no fillers, plasticisers or additives of any kind with the exception of carbon black.

The geomembrane shall be placed on the side slopes, base and interphase bunds. The thickness of the geomembrane shall be 2.0mm. IT shall be anchored within trenches around the perimeter and intercell bunds.

The geomembrane material shall meet the minimum requirements set out in the table in Table 11.1

Table 11.1 Geomembrane Material Requirements

	Parameter	Test Method	Specification Textured HDPE 2.0mm
1	Thickness	ASTM D1593	2.0 ± 10% mm
2	Carbon Black Content	ASTM D1603	>2.0% by mass
3	Carbon Black Dispersion	ASTM D3015	A1, A2 or B1
4	Density	ASTM D1505A	940 ± 1% kg/m^3
5	Tensile Properties	ASTM D638, Type IV, 2ipm	
	(Tensile testing to be performed in longitudinal and transverse directions)		
	Stress at yield		>175lb/in width (31 N/mm)
	Stress at break		>100lb/in width (17 N/mm)
	Elongation at yield		>13%
	Elongation at break		>100%
6	Melt Flow Index	ASTM D1238E	0.1 to 1.1g/10min (smooth test) <2g/10min (textured sheet)
7	Puncture Resistance	FTMS 101 Method 2065	450N

The geomembrane shall be free from cuts, holes, blisters, abrasions or other surface blemishes or defects. The Contractor shall include with his completed Tender, a statement of which manufacturer of material he proposes to use and shall include a schedule of results of independent laboratory testing which show that the minimum requirements set out in Table 11.1 can be met by typical material of the type to be used.

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12.1.1.2 Delivery, handling and storage

The material shall be delivered, handled and stored in accordance with the manufacturer's recommendation taking care to protect the material from damage and contamination. Each roll of geomembrane delivered to site shall be identified with the name of the manufacturer, the product name and type, the thickness, the batch number, the length and he date of manufacture. Any protective coatings shall not be removed until the material is ready to be incorporated into the works.

12.1.1.3 Manufacturer's quality control

The Contractor shall include with his completed Tender a summary of quality control procedures undertaken by the manufacturer at his production facility. The summary shall include the parameters checked and the frequency of the checks.

The Contractor shall supply a quality control certificate for each batch of material delivered to site. The certificate shall contain the following information as a minimum.

12.1.2 Conformance testing

As soon as practicable after the delivery of geomembrane to site, the Contractor shall label and cut a sample 1m wide across the entire width of selected rolls under the direction of the Engineer.

The Contractor shall provide a sample to be dispatched to an approved geosynthetics laboratory for conformance testing of the geomembrane. Samples shall be selected at a frequency of 1 per 10000 m^2 of material delivered to site, or as detailed by the Engineer. The Contractor shall include with his completed tender a statement of which geosynthetic laboratory he proposes to use. All the parameters listed in Table 11.1 of this specification will be tested. The Contractor shall furnish to the Engineer a copy of the laboratory test results immediately on receipt and within seven days of samples being taken.

If testing shows that the geomembrane does not meet any one of the minimum requirements listed in Table 11.1, then this may be cause for rejection of the material from that roll. The Contractor's attention is drawn to the need for a rapid turn round of laboratory results in this connection. Any repairs or other works occasioned by the failure of the geomembrane to meet the minimum requirements listed in Table 11.1 shall be carried out at the Contractor's expense.

The Engineer may at his discretion accept material from elsewhere on that roll if the Contractor can demonstrate through further laboratory testing at a geosynthetic laboratory approved by the Engineer that his material does meet the acceptance criteria contained in Table 11.1. Such further testing shall be undertaken at the Contractor's expense.

12.1.3 Contractor's experience

The Contractor shall have considerable experience of installing geomembrane of the type specified for the Works. The contractor shall include with his completed Tender a summary of his experience with the specified materials including an estimate of the total geomembrane area installed by him in the United Kingdom over the past 12 months.

12.1.4 Geomembrane deployment

The Contractor shall submit a detailed Geomembrane Panel Layout Plan showing the proposed layout and sequence of geomembrane placement not less than one week prior to commencing installation. Geomembrane panels shall be installed in accordance with the Layout Plan as approved by the Engineer.

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The Contractor shall arrange the panels so that the seams are aligned parallel to the line of maximum slope (i.e. normal to contours), whenever practicable in accordance with accepted good practice.

The free edges of each panel shall be adequately weighed down with sand bags, tyres or by other means approved by the Engineer in readiness for seaming.

12.1.5 Temporary surcharge

The Contractor shall be responsible for the geomembrane at all times during the Contract and shall adopt whatever measures are necessary to ensure its stability and protect it from damage. These measures shall include the use of sufficient temporary surcharge in the form of durable sandbags, tyres or similar weights without sharp edges, to be placed on the geomembrane immediately after laying and before seaming to prevent slipping and damage by wind or other agents prior to covering. Any problems arising from the Contractor's failure to secure the geomembrane adequately during the contract shall be remedied at the Contractor's expense. In this regard the Contractor's attention is drawn to the need to provide adequate restraint at free edges of sheet material before anchoring or welding to the adjacent seam, in order to prevent uplift by wind. If tyres are used as temporary surcharge the contractor shall remove them off site at the completion of the installation works.

12.1.6 Thickness

As part of the project Quality Assurance programme, the geomembrane thickness will be measured at intervals by the Engineer for each panel. The thickness tolerances are given in Table 11.1 of this specification. Variation of geomembrane thickness outside these tolerances may be cause for rejection of the affected geomembrane. The rationale for thickness acceptance shall be:

a) No single thickness measurement shall exceed the stated tolerances.
b) The average of the Engineer's measurements across a given roll width shall be greater than the specified thickness (2.00mm).

12.1.7 Seaming

General

The Contractor shall submit method statements not less than one week prior to commencing installation, detailing the following as a minimum.

i. Proposed technique or techniques and their proposed applications
ii. Proposed seaming machinery.
iii. Overlap widths and overlap preparation prior to seaming.
iv. Proposed acceptable temperature ranges for extrudate and/or hot wedge.
v. Proposed acceptable maximum seaming seaming speed if automated machinery to be used.

Trial Seams

The Contractor shall perform trial seams with each seaming machine and operator at least at the start of each shift, after every four hours of operation and also following any period of machine shutdown or change of operator.

The trial seams shall be at least 2m long in the case of extrusion seams and at least 3.5m long in the case of fusion seams. On completion of the trial seam, the Contractor shall cut four 25mm wide field tabs normal to the seam spaced along the seam length. The tabs shall be subjected to field qualitative destructive testing using a tensiometer. Three of the four tabs shall be tested in peel mode with the fourth sample tested in shear mode.

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If a trial seam fails field destructive testing as specified above then the seaming machine and the operator shall not be allowed to perform field seaming until the deficiencies are corrected and both machine and operator have achieved a passing trial seam. Trial seaming and destructive testing will be observed by the Engineer.

Field Seams
The Contractor shall perform field seams only after satisfying trial seam conditions as specified in Section 11.1.9.2 of this Specification. The Contractor shall ensure that all pre-treatment measures (eg grinding and cleaning), are carried out and that extrudate and/or wedge temperatures are maintained within a range approved by the Engineer.
The Contractor's attention is drawn to the following stipulations:

i. Seaming is not allowed during rain or snow unless proper precautions are made to allow the seam to be made on dry geomembrane materials.
ii. Seaming above saturated soil is not acceptable.
iii. Ponded water on the soil surface beneath the geomembrane is not acceptable.
iv. Seaming above frozen ground is not acceptable.
v. Ambient air temperature for seaming should be above 25°C.

All field seams shall be completed to the back edge of the anchor trench, ie the edge furthest away from the slope or toe bund. Any seam defects falling within the anchor trench shall be repaired in accordance with Section 11.1.11 of this Specification.

During construction the specified overlap shall be clearly marked on the edge of the underlying sheet prior to seaming. Failure to maintain the minimum overlap may be cause for rejection of the seam.

12.1.8 Sampling and testing

Non-destructive testing
The Contractor shall perform non-destructive testing along the entire lengths of all field seams including patches and repairs. The Contractor shall submit not less than one week prior to commencing installation a method statement detailing his proposed non-destructive test technique or techniques and their proposed applications.

For air pressure testing of fusion seams the test length should be sealed at both ends and an approved pressure feed divide inserted into the air channel. The channel should then be pumped to a pressure of between 25 and 30 psi and allowed to stabilise for one minute. The test will have deemed to have failed of the loss of pressure exceeds 3 psi over a five minute period following stabilisation. The test will have deemed to have passes if the loss of pressure is less than 3 psi over a five minute period.

For vacuum box testing each section of the seam should be tested and observed for a period of not less than 10 seconds.

In the event of a field seam failing non-destructive testing the Contractor shall identify and repair the failed area in accordance with Section 11.1.11 of this Specification. The Contractor shall then subject the repair to further non-destructive testing until the repair shall pass the test.

The Contractor shall advise the Engineer when he is ready to commence non-destructive testing and shall not perform non-destructive testing unless the Engineer is in attendance.

Qualitative destructive testing
The Contractor shall cut a 25mm wide field tab from the beginning and end of each completed field seam and shall subject it to qualitative destructive testing in peel mode using a tensiometer.

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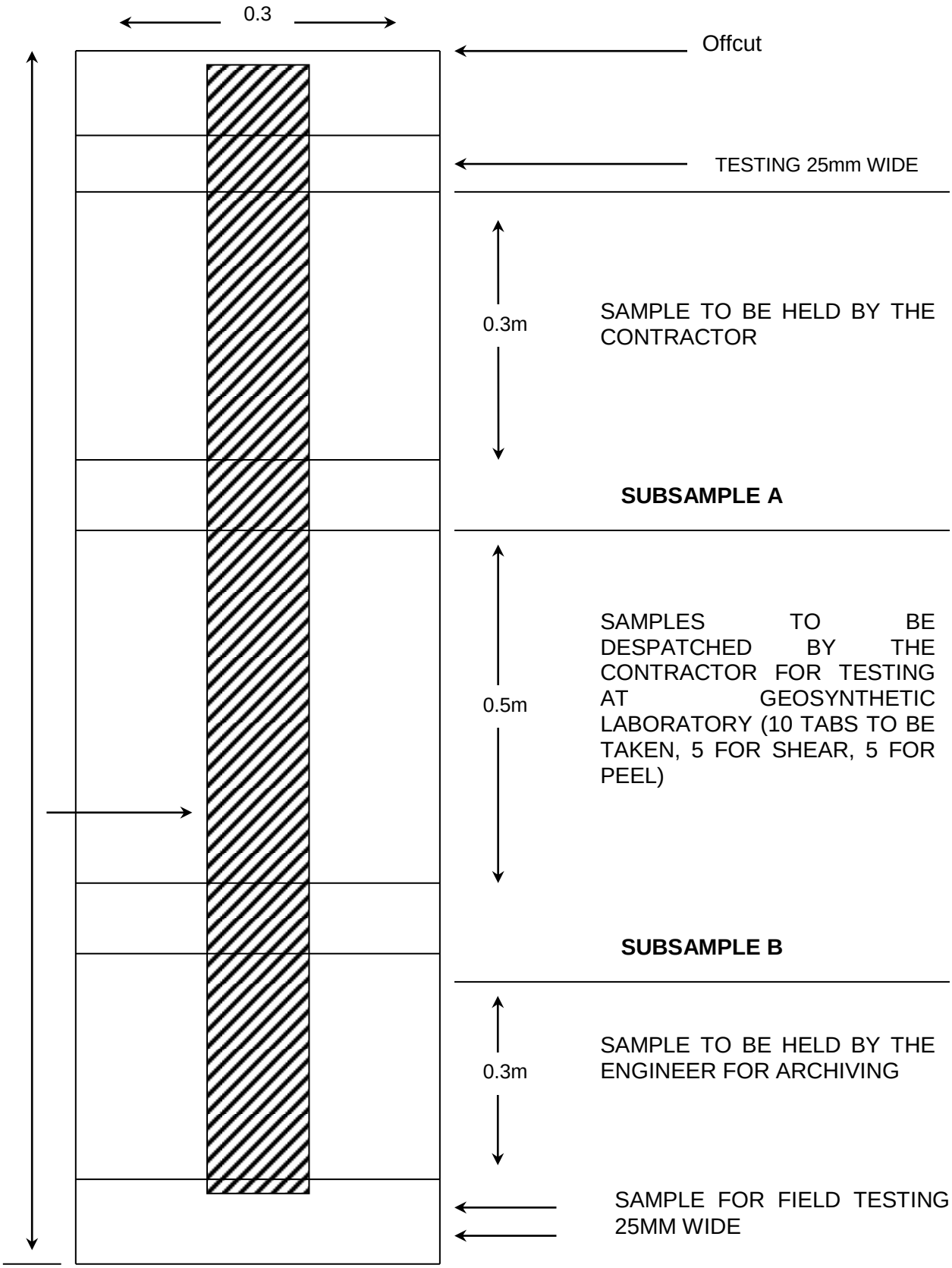
The seam will be deemed to have passed qualitative destructive testing if the failure occurs solely in the parent material and does not enter the seam. The seam will be deemed to have failed qualitative destructive testing if any of the failure enters the seam. Figure 7.1 and Figure 7.2 show the destructive sample test codes for both extrusion and fusion welding.
If a field tab fails qualitative destructive testing, the Contractor shall either:

1. Reconstruct the seam between two tabs shown to have passed qualitative destructive testing.
2. Cut further tabs from 3m to each side of the failed tab and subject these to qualitative destructive testing. If these tabs pass qualitative destructive testing the Contractor shall reconstruct the seam between the passed locations in accordance with Section 11.1.11 of this Specification. If either sample fails, the Contractor shall cut and test further field tabs until he can identify an area bounded by two passed locations. The Contractor shall then reconstruct the failed seam in accordance with Section 11.1.11 of this Specification.
3. The Engineer reserves the right to request the cutting and destructive testing of further field tabs at any locations along the length of a seam.

Quantitative destructive testing
The Contractor shall cut laboratory samples from the field seams when instructed by the Engineer and in any case at a frequency not exceeding one sample per 200m of seam performed by an individual machine.

The Contractor shall divide the sample shown in Figure 11.1 and release sub-sample C to the Engineer for archiving.

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NB: THE SEAM SHALL BE CENTERED PARRALLEL TO THE WIDTH OF THE SAMPLE

Figure 11.1

The Contractor shall without delay despatch sub-sample B to an approved geosynthetic laboratory for destructive testing in accordance with the table shown in Figure 11.1. The

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Contractor should note that five tabs should cut for peel tests and five tabs for shear tests. The laboratory shall report quantitative results and the mode of failure for the tests carried out. Mode of failure shall be described in accordance with Figure 11.1. The Contractor shall issue copies of the test results certificates to the Engineer immediately upon receipt, within 48 hours of cutting the sample from the installation.

Table 11.1 Schedule for Seam Destructive Testing
Schedule of Destructive Tests - Fusion Weld

Parameter	**Test Method**	**Specification Textured to Textured**
Tensile Properties	ASTM D638 Type IV, 2 lpm	1 lb/inch width
Peel Test		>120 (21.0N/mm)
Shear Test		>160 (28.0N/mm)

Each set of destructive tests to consist of pulling of five No. standard tabs.
Test results to include a description of the mode of failure.

The ASTM standard 'dog-bone' cannot be used for this test. The test specimen should be prepared to a uniform one inch width in the test area, and should be wider at the clamp points to prevent failure.

Schedule of Destructive Tests - Extrusion Weld

Parameter	**Test Method**	**Specification Textured to Textured**
Tensile Properties	ASTM D638 Type IV, 2 lpm	1 lb/inch width
Peel Test		>104 (18.2Nmm)
Shear Test		>160 (28.0N/mm)

The seam will be deemed to have passed quantitative destructive testing if in four out of five of the tabs:

1 The failure occurs solely in the parent material and does not enter the seam.
2 The peel strength exceeds that indicated in Table 11.2.
3 The shear strength exceeds that indicated in Table 11.2.

The seam will be deemed to have failed quantitative destructive testing if in more than one out of five tabs:

1 Any of the failure enters the seam.
2 The peel strength is less than that indicated in Table 11.2.
3 The shear strength is less than that indicated in Table 11.2.

If a seam fails quantitative destructive testing the Contractor shall investigate the seam to each side of the failed sample as specified in Section 11.1.10.2 of this Specification. The Contractor shall cut further laboratory samples from each side of the failed section and perform laboratory tests upon them at his own expense until the failed seam is bounded by two passed locations.

The Contractor shall then reconstruct the failed seam in accordance with Section 11.1.11 of this Specification. The Engineer may at his discretion observe laboratory destructive testing

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in which event the Contractor shall arrange permission for access to the approved laboratory.

The Contractor shall furnish the Engineer with a copy of the formal report from the independent testing laboratory detailed the procedures used for testing and including a summary of all results. This report shall be furnished to the Engineer within one week of the completion of the works.

12.1.9 Repairs, starches and cap-strips

All discontinuities in the geomembrane (whether caused by damage or failure of geomembrane or seams to conform with Specification, or of sampling or testing or other factors), shall be repaired by the Contractor in the following manner:

Point defects
The area shall be prepared in accordance with Section 11.1.9.3.1 and an extra layer of extrudate applied.

Large faults
The faulted area shall be cut back to remove all imperfections and shall be overlain with a single piece of compatible geomembrane to give a minimum overlap of 150mm in all directions. The area shall then be prepared in accordance with Section 11.1.9.3.1 and seamed in accordance with Section 11.1.9 of this Specification.

Seam faults

a) Faulted extrusion seams shall be overlain with a single piece of compatible geomembrane with a minimum overlap of 100mm in all directions to form a cap strip. The repair may then be completed as for large faults.

b) Faulted fusion seams hall be cut back to remove the upper flap, prepared in accordance with 11.1.9.3.1, and extruded in accordance with Section 11.1.9 of this Specification.

The Contractor shall test all repairs in accordance with Section 11.1.10.1 of this specification.

12.1.10 Construction details

The geomembrane shall be installed to the grades shown on Drawing No. 4 (not included in this document). The anchor trenches shall be constructed in accordance with Drawing No.4.

Shoulders of the anchor trench shall be slightly rounded when a geomembrane adjoins the trench to minimise sharp bends in the key in trench. The geomembrane shall be installed and welded to the back of the anchor trench as shown on the drawing. Anchor trench backfill shall be selected excavated material and installed in lifts not exceeding 150mm and compacted with a wacker plate or other means approved by the Engineer.

As can be seen from the above specification the Project Engineer requires a lot of information from the source of resin through the manufacturing phase, delivery handling and storage, installation Contractors experience, geomembrane deployment, seaming, destructive testing, repairs, patches and finally as-built drawings which show the position of every panel used in the project, every weld seam and every destructive sample taken. There is a lot of time and effort involved on the Installation Contractors part in providing the above information but it is important for all parties involved in a project that this information is available and recorded.

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12.2 Completing welding reports

Attached below in Section 11.3 is a list of the main reports that are required to be completed for all containment projects and it would be considered good practice to complete them for all installations. These forms should be completed on a daily basis as it is good practice and because this information can provide valuable information to a Project Engineer regarding the smooth running or otherwise of a project. From a quality point of view a glance at any of the attached reports will allow the reader to form an accurate picture of the quality of the installation to date.

An Installation Company and Project Engineers can learn a lot about the affects on the welding progress and quality on various different types of sub-grade by studying the Liner Installation Welding Report. The problems encountered when welding geomembrane on a sub-base of Bentonite enriched soil, for example, can be very different to those problems encountered when welding on a clay sub-base. The information involved in the Weld Reports and the Destructive Welding Reports will clearly show the differences and difficulties encountered, if the information is recorded correctly.

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Liner Installation Destructive Testing Report

Project: ____________

Sample	Seam	Machine ID	Date	Peel (A)		Peel (B)		Shear		Sample
Ref	Ref	Weld Type (Ext/Fus)	Seam Formed	Strength (lbs/inch width)	Code*	Strength (lbs/inch width)	Code*	Strength (lbs/inch width)	Code*	Pass/Fail

*See Contract Specification for break code

Peel (min)	**lb/inch width**
Shear (min)	**lb/inch width**

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Liner Installation
Daily Summary

Project:

Date:		**Panel Reference**	**Roll Number**	**Subgrade Accep. Initials**	**Panel Dimensions**		
Weather am:					**L (m)**	**W (m)**	**A (m²)**
Weather pm:							
Hrs.							
Lining Foreman:							
Lining Technicians:							
Hrs.	**Hrs.**						
1	**9**						
2	**10**						
3	**11**						
4	**12**						
5	**13**						
6	**14**						
7	**15**						
8	**16**						
Area Installed Today :	**(m²)**						
Running Total Area Deployed:	**(m²)**						
Length of Fusion Weld Today:	**(m)**						
Length of Extrusion Weld Today:	**(m)**						
Lab Destructive Samples Sent:	**No.**						

D.S. Reference **From Seam Reference**

Details/Extra Work: **Repair**

Details/Extra Work:

Repair Report

Reference	**Reference**	**Seam Technician**	**Panel**	**Repair**	**N.D.T**	**Details**
			Pass (intls)			

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Certificate of Acceptance of Soil Subgrade Surface

Project Name: _____

Project Number: _____

Owner: _____

Location: _____

I the undersigned, a duly appointed representative of our company., have visually inspected the soil subgrade surface described below and found it to be an acceptable surface on which to install geomembrane.

This certification is based on observations of the surface of the subgrade only. No subterranean inspections or tests have been performed by our company, and our company makes no representations or warranties regarding conditions which may exist

Area being Accepted: _____

_____

Company Representative:

Date: _____

Signature: _____

Name: _____

Title: _____

Owner Representative:

Date: _____

Signature: _____

Name: _____

Title: _____

Company: _____

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Material Delivery
Inventory Checklist

Project:

	COMPLETE ROLL NUMBER	BATCH NUMBER	ROLL SIZE	DAMAGE/REMARKS
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
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13 Appendix 2

13.1 Risk assessment associated with geomembrane installation

13.1.1 Operation: Excavations and earth moving

Hazards:

- Falling into excavations.
- Collapsing of sides of excavations or steep slopes.
- Asphyxiation or poisoning by gases in excavations.
- Falling material eg from excavator or dumptruck.
- Personnel crushed or driven over by plant.

Required control measures:

Physical/systems of work
- Fence off excavations which are left open.
- Do not enter deep (>1.2m) or unstable excavations which are not supported.
- Use gas monitors in deep excavations.
- Position plant and vehicle exhausts downwind when possible.

Personal protective equipment
- Hard hats.
- High visibility clothing.

Training
- Induction and tool box talks for all site staff, Plant operators and Banksmen to be adequately trained.
- Especially new or inexperienced.

Information and reference
See confined spaces risk assessment.

Record
- Record of training and tool box talks to be held for each site.
- Register of excavation inspections to be maintained.

Monitoring
Monitoring of training and working methods by site supervisor

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13.1.2 Operations: Loading/unloading and stacking materials

Hazards:

- Falling loads eg equipment failure or poor slinging causing load to slip or drop.
- Swinging loads eg cranes sluing or jibbing, or lifting when rope not vertical.
- Collapsing stacks of rolls of lining material.

Required control measures:

Physical/systems of work

- Lifting to be directed by a trained Banksmen.
- Loads to be slung by a trained Banksmen or Slinger.
- Equipment to be suitably rated and certified.
- Avoid standing under loads or between a load and a hard place.
- Rolls to be placed to reduce risk of rolling.

Personal protective equipment

- Hard hats.

Training

- Lifting plant to be operated by trained and certified personnel.
- Loads to be slung and directed by suitably trained site staff.
- Induction and tool box talks for all site staff.

Information and reference

Construction (Lifting Operations) Regulations 1961.

Record

- Records of training to be maintained.
- F91 Register for plant and lifting gear to be maintained on site for owned equipment, or inspected for equipment not owned.

Monitoring

Monitoring of training and working methods by site supervisor.

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13.1.3 Operations: Transporting and deploying lining materials

Hazards:

- Persons hit by materials being unrolled down slopes.
- Slipping/falling over on smooth liner.
- Persons hit, knocked over or dragged by wind blown liner.
- Persons hit by plant or rolls of material in transit on site.

Required control measures:

Physical/systems of work

- Ensure no persons are in area in front or on downhill side of roll to be unrolled.
- Lining materials to be anchored eg with sandbags as deployment progresses.
- Do not handle or lay unrolled material in strong winds.
- Use rope ladders on slopes and safety ropes if appropriate.
- Rolls in transit on site to be guided by a suitable person eg Banksmen.

Personal protective equipment

- Hard hats.
- Safety footwear.
- Rope ladder and safety ropes if appropriate.

Training

- Induction/tool box talks.

Information and reference

See risk assessments on loading/unloading.

Record

- Record of Induction/tool box talks.

Monitoring

Regular monitoring by site supervisor.

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13.1.4 Operations: Cutting and preparing lining materials

Hazards:

- Serious cuts and minor injuries from craft knifes.
- Injuries from contact with sander discs eg fingers limbs.
- Eye injuries and minor injuries from flying particles during sanding.
- Inhalation of dust, particles and fibres.
- Burns and fumes from cleaning fluids.

Required control measures

Physical/systems of work

- Use of correct citting equipment for matirial.
- Maintain knives in good condition.
- Cut away from body.
- Wear gloves and eye protection when grinding.
- Wear dust masks during dusty operations.
- Ensure other personnel are not put at risk by operations.

Personal protective equipment

- Gloves.
- Eye Protection.
- Dust masks.
- (All as appropriate).

Training

- Induction training and tool box talks.
- Training and certification for staff to mount abrasive wheels.

Information and reference

- Abrasive Wheels Regulations (1970).
- Provisions and use of Work Equipment Regulations (1992).
- See COSHH assessment for cleaning fluids.

Record

- Maintain record of training and certification.

Monitoring

Monitoring of training and working methods by site supervisor.

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13.1.5 Operations: Seaming of lining materials

Hazards:

- Burns from welding equipment, hot welds or extrudate.
- Burns from hot air blowers.
- Fingers crushed in rollers of wedge welders.
- Fingers or limbs injured by stitching machines.
- Inhalation of bentonite dust from joining GCLs.

Required control measures:

Physical/systems of work

- Only suitably trained and qualified personnel to use welding and stitching equipment.
- Wear suitable protective clothing.
- Keep hands etc. clear of hot machine parts and welds.
- Equipment to be properly maintained.

Personal protective equipment

- Gloves whenever possible.
- Dust masks when handling bentonite.

Training

- Training in the safe use of all equipment for welding techniques.
- Induction/tool box talks for all other site staff.

Information and reference

- Bentonite dust COSHH assessment/data sheet.

Record

- Record of training and tool box talks.

Monitoring

Monitoring of training and working methods by site supervisor.

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13.1.6 Operations: Testing lining seams

Hazards:

- Electrocution from HVE spark test equipment.
- Burns from gas torch.

Required control measures:

Physical/systems of work

- Only trained personnel to use spark test equipment and gas torches.
- Switch off / disconnect when not actually in use.

Personal protective equipment

- Gloves when possible.

Training

- Induction training and tool box talks.

Information and reference

Record

- Record of training and tool box talks.

Monitoring

Monitoring of training and working methods by site supervisor.

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13.1.7 Operations: Working on landfill sites

Hazards:

- Infection with diseases.
- Poisoning with toxic substances or gases.
- Physical injury from sharp objects in refuse.
- Injury or death from heavy plant eg waste compactors.
- Risk of fire / explosion from flammable landfill gas.

Required control measures:

Physical/systems of work

- Seek information from site owner regarding types of waste likely to be encountered.
- Avoid direct contact with refuse or leachate.
- Keep away from landfilling areas if possible.
- No scavenging or collecting to be permitted.
- Wash thoroughly before eating and drinking.
- Use gas detector before spark testing.
- No smoking.

Personal protective equipment

- Gloves.
- Boots.
- Overalls.
- Dust masks.
- High visibility clothing.
- (where close contact with refuse or leachate is unavoidable).

Training

- Induction training and tool box talks.

Information and reference

- DOE Waste Management papers.
- BDA guidelines (British Drilling Association).

Record

- Record of training and tool box talks.

Monitoring

Monitoring of training and working methods by site supervisor.

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13.1.8 Operations: Working on petroleum / chemical sites

Hazards:

- Fire, explosion, toxic and corrosive substances.

Required control measures:

Physical/systems of work

- Seek site specific details from site owner / manager and agree safe working procedures with site owner / manager.

Personal protective equipment

Training

- Arrange training / induction for all site staff with site owner or obtain site rules and carry out own training.

Information and reference

Record

- Maintain record of training and certification.

Monitoring

Monitoring of training and working methods by site supervisor.

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13.1.9 Operations: Working in confined spaces

Hazards:

- Asphyxiation due to oxygen or toxic gases.
- Fire or explosion due to inflammable / explosive gases.
- Other physical hazards eg deep tanks, slippery surfaces, poor lighting etc.
- Site specific risk assessment required.

Required control measures:

Physical/systems of work

- Assessment of risk and necessary precautions to be undertaken by trained and suitably qualified person.
- Obtain information from site / manager.
- Site specific method statement to be developed, likely to include, as a minimum, use of potable gas detector to ensure safe atmosphere before and during entry into a confined space.
- Develop 'permit to enter' system with site owner, if appropriate.

Personal protective equipment

- Gas detector.
- Possibly man riding winch.
- Escape breathing apparatus or full breathing apparatus.

Training

- Site supervision in charge if operations to be trained and qualified.
- All other personnel to have suitable training.

Information and reference

Health and Safety Executive, Guidance Note GS5.

Record

- Maintain record of training.

Monitoring

Regular monitoring by site supervisor.

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13.1.10 Operations: Using scaffolding and mechanical materials hoists

Hazards:

- Scaffold collapsing / overturning leading to serious injury or death.
- Falling personnel or materials leading to serious injury or death.
- Failure or incorrect use of hoists leading to serious injury or death.

Required control measures:

Physical/systems of work

- Scaffolds not to be used until they are complete and have been inspected.
- Scaffold towers to be erected and used only in accordance with suppliers instructions, normally with ladder fixed inside tower.
- Only certified lifting equipment to be used.

Personal protective equipment

- Hard hats.

Training

- Only suitably trained and qualified personnel are to erect and inspect scaffolding and lifting equipment.

Information and reference

- Health and Safety Executive, Guidance Notes GS15, GS31 and GS42.
- Construction (Working Places) Regulations 1961.
- Construction (Lifting Operations) Regulations 1961.

Record

- F91 register of inspections to be maintained.

Monitoring

Monitoring of training and working methods by site supervisor.

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13.1.11 Operations: Working close to water

Hazards:

- Drowning.
- Infection with diseases.
- Site specific risk assessment required.

Required control measures:

Physical/systems of work

- Assessment of risk and necessary precautions to be undertaken by trained and suitably qualified person.
- Personnel to carry Instruction Card on diseases for work near water.

Precautions may include:

- Fencing off of water.
- Provision of buoyancy aids.
- Strategic placing of ropes for life lines.
- Provision of boat in extreme cases.

Personal protective equipment

- Life jackets.
- Buoyancy aids.
- Harnesses.
- Ropes.
- (When appropriate).

Training

- All personnel to have site specific induction training and tool box talks.

Information and reference

Record

- Maintain record of training.

Monitoring

Monitoring of training and working methods by site supervisor.

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13.1.12 Operations: Manual handling and lifting

Hazards:

- Risk of back injury.
- Risk of injury to limbs.

Required control measures:

Physical/systems of work

- Weights in excess of 25kg should be mechanically handled whenever possible.
- Any unavoidable hazardous manual handling is to be assessed.

Personal protective equipment

Training

- Induction and tool box talks for all site staff, especially new or inexperienced staff.

Information and reference

The Manual Handling Operations Regulations 1992.

Record

- Keep record of assessments, except for simple operations.

Monitoring

- Monitoring of training and working methods by site supervisor.

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13.1.13 Operations: Use of electricity on site

Hazards:

- Electric shock, possibly fatal.

Required control measures:

Physical/systems of work

- RCD fitted to all generators, appliances and cables.
- All equipment to be regularly maintained and inspected by a competent person.
- Use safe ampage /current whenever possible
- All equipment to be tagged with retest date .

Personal protective equipment

Training

- Induction and tool box talks for all personnel, specific training for competent person.

Information and reference

Electricity at Work Regulations 1989.

- Record
- Record of training and equipment inspections.

Monitoring

- Site supervisor or nominated competent person to check on safe systems of work.

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