TRIPLATE®

The Ultimate Solution for Welding Aluminium to Steel

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For a number of years now, shipbuilders have gratefully taken advantage of the availability of pre-produced transition joint assemblies to make welds between aluminium and steel.

The older, more traditional methods of joining, like riveting and bolted joints have fallen from favour due to the fact that in a few years considerable corrosion can occur aided by capillary action caused mainly by the widely differing thermal expansion coefficients of aluminium and steel. In spite of efforts to prevent it, this phenomenon allows seawater to seep into the dissimilar metal joint, thereby resulting in severe corrosion. In many cases the only way to maintain the ship in a sea-worthy condition is to completely replace the aluminium-steel transition or, in some cases, to replace the complete wheelhouse.

Transition joints were mainly produced by the explosive weld-bonding process carried out in the open air in remote locations. This explosive process is in fact a cold pressure welding process, where investigations have shown that superior joint properties can be achieved if the process takes place under vacuum. As this is very difficult to achieve in practice, at the present time only one manufacturer in the world has the capability to produce explosive clad products in a vacuum: Shockwave Metalworking Technologies b.v. in Holland.

Atmospheric	**Vacuum**
Coarse oxide agglomerations with porosity at the steel-aluminium interface	100% dense, homogeneous joint
Oxide agglomerations & porosity initiate fracture	Does not apply
Oxide agglomerations & porosity can eventually cause corrosion, in spite of protective coatings	Does not apply.
Bending of aluminium-steel strips can be difficult: Sidebend radius: 10 x stripwidth	Very good formability: Sidebend radius: 5 x stripwidth
Production control is limited by variable weather conditions	Optimal process control due to constantly reproducible vacuum conditions
Aluminium-steel joint is hard making sawing and forming difficult	Easy sawing and forming thanks to ductile aluminium-steel joint

Table 1

Cladding Process

To simply and quickly understand what happens during the explosive bonding process refer to Figure 1.

An empirically calculated stand-off space between two plates to be bonded is created by placing polystyrene blocks between them. Thus the upper plate is accelerated down onto the lower plate during the explosion. The velocity VP varies with the type and the quantity of explosive material used and the weight of the upper plate. It is most important that the stand-off distance SB is equal to SB1. At the collision point S an extremely high pressure is reached during the explosion, which causes the metal surfaces to become super-plastic enabling the pressure wave to break up the oxide surfaces. These oxide particles are driven out of the advancing detonation front, together with the air to produce the so-called jet.

The result is that the two metal surfaces are pressed together with huge force, locally interlocking the different atomic structures. In this way, by definition, a very strong atomic bond is formed between two metals like aluminium and steel.

After the cladding process the plates are flattened and then sawn into strips which are used as an intermediate layer for welding aluminium alloy superstructures to steel hulls.

As these aluminium-magnesium alloys are too hard to form a strong explosive bond with the steel, a softer commercially pure aluminium sheet is positioned in the sandwich layer between them, which gives us the name Triplate.

Atmospheric versus Vacuum Cladding

Although atmospheric cladding is an effective process there appear to be advantages if the explosive bonding process is carried out under vacuum.

Apart from the fact that the vacuum process does not cause ”noise nuisance”, its greatest advantage is that it is not necessary to remove any air in the advancing, explosive-bonding jet.

For this reason less violent explosives can be used for bonding and this, in turn, produces a smoother wave bond between the aluminium and steel which is often barely visible.

Fig 1: The upper plate is accelerated down onto the lower plate during the explosion

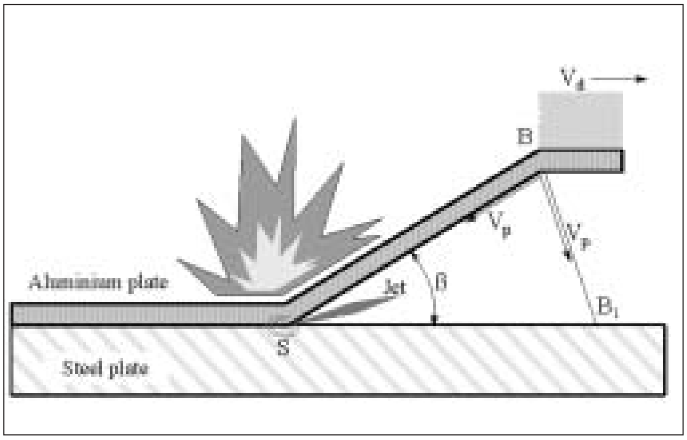
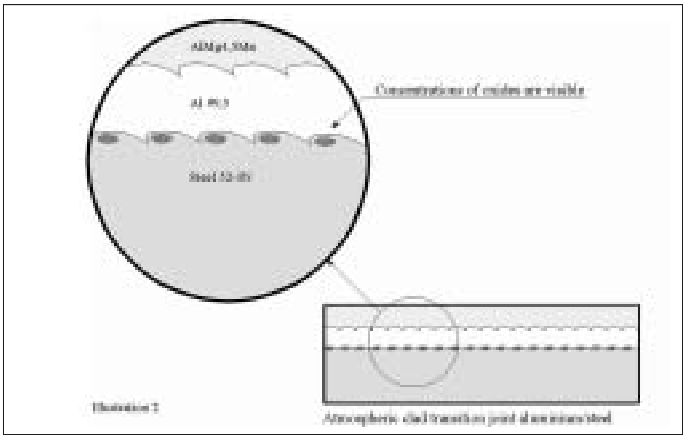


Fig 2: A wave motion can trap oxides, resulting in “holes” visible in the bond zone



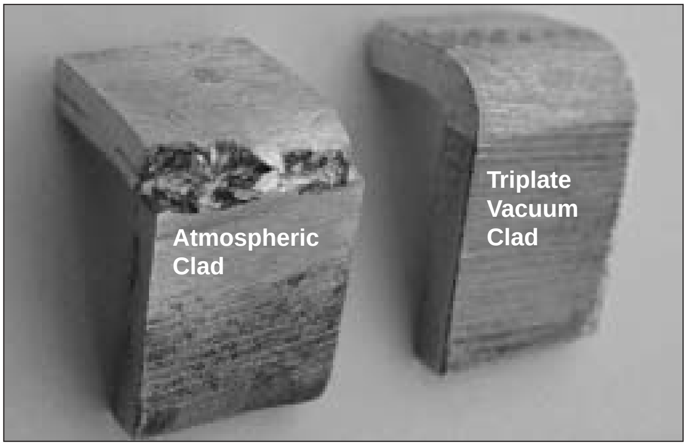


Fig 3: Oxide agglomerations subjected to the bend test fracture at these points

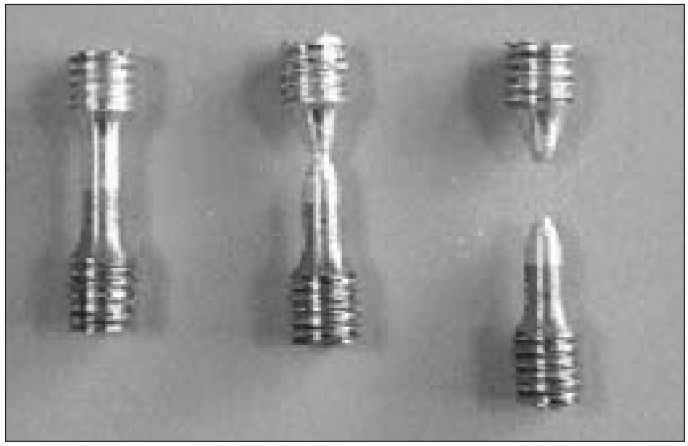


Fig 4: The fracture in a tensile test sample is not at the joint itself

A turbulent wave motion can trap oxides, resulting in "holes" being visible in the bond zone. These are in fact, undesirable agglomerations of oxides as shown in Figure 2. Oxide agglomerations are visible with the naked eye. If this product is subjected to the hammer bend test according to MIL J24445A it can be seen in Figure 3 that the fractures initiate at these points. Vacuum clad products do not have this problem.

A second advantage is the cost reduction in the quantity of explosives needed and the reduced wear of saw blades due to the absence of abrasive oxides in the bond area.

Additionally, the fact that favourable weather conditions and long transport routes to isolated cladding sites are not required, gives the vacuum process an advantage.

It is therefore apparent that in spite of the initial investment required for a vacuum chamber the cost is cheaper than atmospheric cladding.

One must not under-estimate the negative effects of weather as temperature and humidity can have a negative influence on the quality of the bond.

At temperatures below 10°C there is a risk of some delamination in the product or even failure to bond at all as the material is not sufficiently ductile during the explosion. Also any condensation of water on the plates due to humidity can cause a poor bond.

Thus, vacuum cladding can only be advantageous due to the constantly reproducible and controllable processing conditions. The fear by some potential users that the clad bond produced by vacuum cladding is inferior due to it being virtually invisible is shown to be unfounded in practice where outstanding mechanical properties, ductility and fatigue characteristics are encountered. The bond of aluminium to steel does not take place due to the interlocking effect of waves (mechanical), but by an atomic bond of the metals. Table 1 shows the comparative properties of atmospheric and vacuum clad products.

Atmospheric Clad Transition Joint

Figure 4 shows that the fracture in a tensile test sample is not at the joint itself, but within the aluminium transition zone. If a sample is exposed to one million cycles of mechanical loading, e.g. a fatigue test then the test sample breaks in the same zone as shown in Figure 4.

These facts have resulted in the largest offshore oil company in Norway specifying Triplate for critical components on platforms due to its superior properties. Triplate has also been granted approval by Lloyd's, Germanische Lloyd's, Rina, Det Norske Veritas, American Bureau of Shipping and Veritas.

An aluminium to stainless steel transition joint can also be produced in a similar way.

Triplate

Triplate consists of a sandwich of three metals namely steel St. 52-3N as base material, aluminium 99.5 (Alloy 1050A) as intermediate layer and the corrosion resistant aluminium alloy AlMg4.5Mn (Alloy 5083) as the upper layer (Figure 5).

It is not possible to weld aluminium directly to steel using conventional fusion welding processes, but by using intermediate strips of Triplate pre-bonded cold via the explosion cladding process, high strength aluminium to steel joints can be achieved using conventional fusion welding processes. Figure 6 shows both the ideal joint configuration and an acceptable one using Triplate. The set-up on the left achieves the lowest heat-input in the transition zone during welding.

Product Forms

Triplate can be produced to various strip widths, but via water jet cutting it is also possible to produce transition pieces to follow complex contours of superstructures. Figure 7 shows a typical piece produced by waterjet cutting. It is obvious that the use of Triplate in this way can have a positive effect on manufacturing costs.

Figures 8 and 9 show some practical applications of Triplate in the shipbuilding industry.

Precautions

The greatest limitation for the combination aluminium/steel is high temperature. Above 315° C undesirable intermetallic compounds occur in the transition zone in the form of aluminium/iron crystals ($AlFe_3$). These brittle compounds adversely effect the mechanical and electrical properties to a high degree. The latter effect may not impair the joint from a construction point of view, but can have serious consequences if the transition joint is incorporated in electrolytic processes like metal production. The problem can be avoided by incorporating a thin barrier layer of titanium in the transition sandwich, but this greatly increases the cost of the Triplate. Figure 10 shows the reduction in shear strength as a function of temperature. It clearly shows the sharp decline in properties after exposure to temperatures above 315°C for 200 hours. For this reason welding configurations illustrated in Figure 11 should be avoided. The fact that this intermetallic layer has a higher electric resistance is clearly indicated in Figure 12 where it rises steeply above 315° C. A good clad joint does not have any increase in electric

Fig 5: Triplate consists of a sandwich of three metals

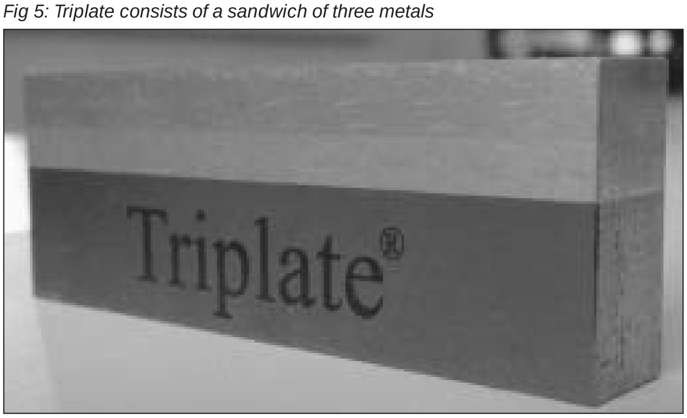
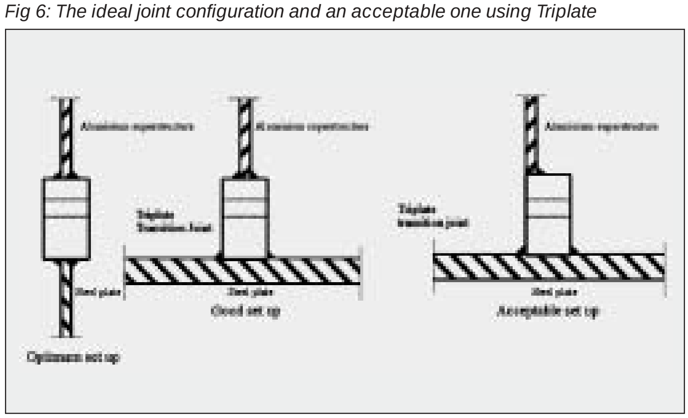


Fig 6: The ideal joint configuration and an acceptable one using Triplate



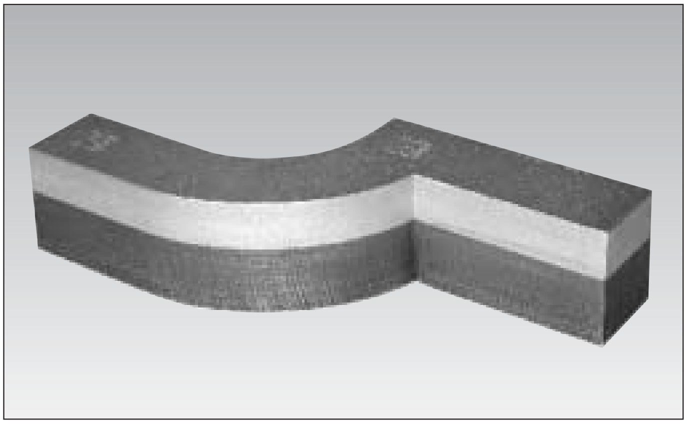


Fig 7: Triplate can be produced to various strip widths

Fig 8 & 9: Practical applications of Triplate in the shipbuilding industry

resistance across the transition zone as the bond is by definition metallurgical and the electric resistance is that of the individual materials.

Mechanical Properties of the Transition Zone

It is important that the mechanical properties of the transition zone are not reduced or the whole construction will be weakened. Here also, the chain is only as strong as its weakest link. Thus it is very important that the transition strips are not pre-heated prior to welding as this would only increase the temperature of the aluminium/steel zone during welding. The dimensions of the transition strips are so calculated that no embrittlement can be produced during normal welding procedures by considering the temperature gradients in the individual metals. The high thermal conductivity of aluminium helps to make this possible. Therefore it is important to first weld the aluminium to the Triplate, followed by the steel.

Temperature Gradient

By using thermocouples or a temperature sensitive coating to observe the temperature during welding it should be possible to guarantee that without pre-heat and by using normal welding parameters the temperature in the transition does not exceed 315° C. This is illustrated in the temperature gradient curve in Figure 13.

In practice it shows the temperature in the transition zone barely reaches 240° C. This presumes that the weld root (land) thicknesses (so called 'a-values'), based on the plate thicknesses being welded, are adhered to.

To achieve a good control of the heat input in the Triplate, a transition strip width of 4 x aluminium superstructure plate thickness should be chosen.

Welding

The aluminium structure can be welded to the transition strip using either the GMAW (MIG) or GTAW (TIG) welding process after the joint surfaces have been cleaned and degreased. If it necessary to brush the aluminium prior to welding it is important to use a stainless steel brush. Brushing is necessary if heavy oxidation, scratches or gouges (often with deposits) are present on the surface.

If official welding procedures for the aluminium and steel welding are to be employed, then AWS D3.5-85, AWS D3.7-83 and MIL-STD-1689 can be used.

It is important that the welds have good penetration and the root land surfaces are smooth and flat. Thus it is recommended to use the welding parameters mentioned in the above procedures which will result in a flat or slightly concave weld bead.

If several passes are required, then it is strongly recommended to allow each one to cool down to reduce over-heating the critical transition zone. The diameter of filler wire should be limited to 1.2 mm maximum.

For both the aluminium and steel joints it is recommended that the horizontal welding position is used wherever possible.

For aluminium welds either pure argon or a mixture of 75% helium & 25% argon are recommended as shielding gas.

Steel welds can be made with stick electrodes (SMAW) or MIG/MAG (CO2) or even filled wire. Maximum electrode diameter should be limited to 2.5 mm to minimize heat-input during welding. For extra safety, a heat-sensitive coating can be applied to the joint to indicate temperature levels.

Strip Dimensions

Triplate can be cut to length using circular saws, band saws or even a hand saw followed by deburring with an abrasive disc or strip.

It is also possible to achieve good results with a band saw as Triplate remains in full view in certain applications like marine constructions. Triplate strip should never be cut to length using thermal cutting equipment.

Butt Welds

To avoid gaps between the ends of the individual transition strips, a butt weld joint can be made as shown in Figure 14.

The remaining unwelded central gap can be closed either by hammering with a dome-headed hammer or by filling with a silicone based putty. In order to be completely certain that no part of the transition zone exceeds the critical temperature of 315° C. it is possible in some circumstances to close the gap without welding, using only hammering or only silicone putty.

In addition it is often possible to accept some very localized formation of undesirable intermetallic compounds during welding as these small areas do not have a harmful effect on the whole construction. Above all, the temperature excursions are so short that the undesirable phases do not have time to form.

Butt welding the transition strips together also gives a greater structural stability and stiffness to the aluminium superstructure than using 100% putty sealing techniques.

Bending Triplate

Horizontal or side-bends can be made in Triplate without problems for a minimum bend radius of 5 x strip width. Vertical bends with the

Fig 9

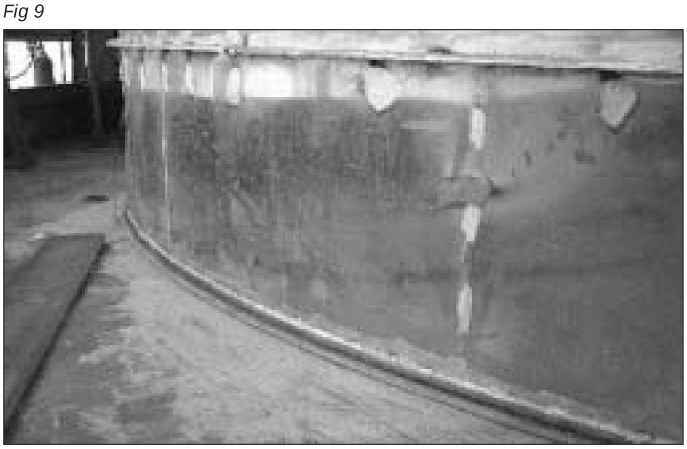
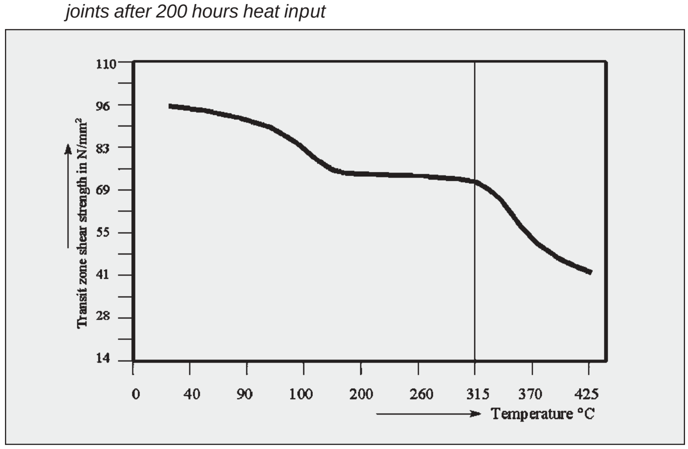


Fig 10: Relationship between temperature and shear strength in aluminium/steel joints after 200 hours heat input



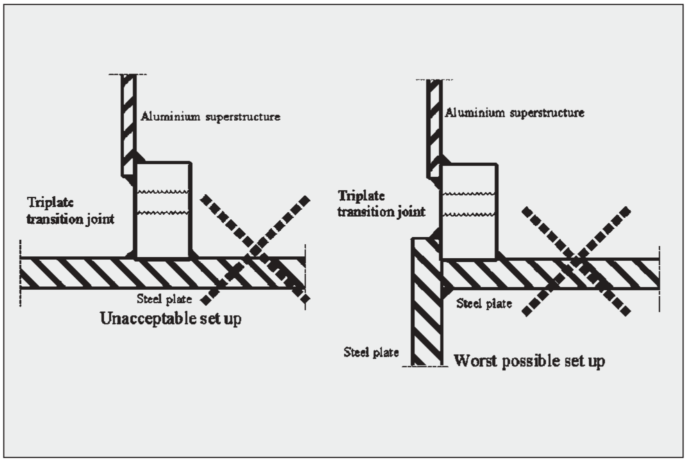


Fig 11: Welding configurations such as illustrated should be avoided

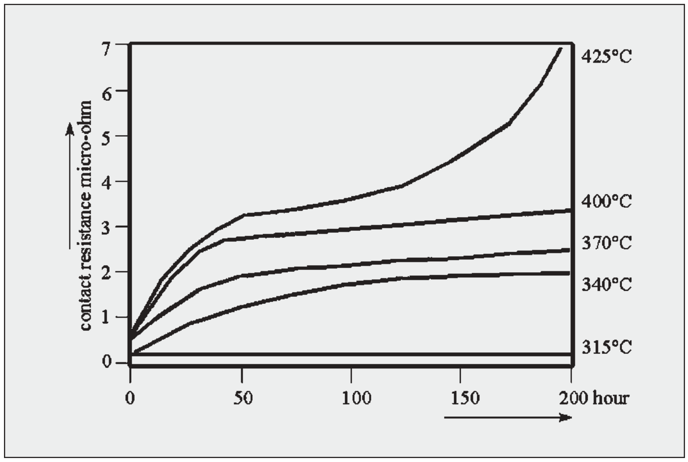


Fig 12: Relation between time, temperature and electrical resistance of transition zone aluminium/steel

aluminium under tension or compression should be limited to a minimum bending radius of 300 mm in both cases.

Coating

All conventional marine coatings to prevent contact with sea water can be used on Triplate on ships. Good corrosion results have also been achieved on non-coated constructions due to the fact that with Triplate no natural crevice is present as is the case with bolted or riveted joints. The crevice effect is even further increased in a riveted construction due to the different thermal expansion coefficients which accelerate the capillary effect.
In all cases it is recommended to apply to the Triplate the same coating as used on the whole construction.

Thermal Expansion Coefficient

As aluminium and steel have widely differing thermal expansion coefficients, 23 x 10^{-6} and 12 x 10^{-6} respectively, one asks the question how this manifests itself in practice. One could imagine the strip would bend like a bimetal strip when exposed to temperature changes.
However the strip does remain straight even during appreciable temperature changes as the following calculation for a typical 40° C temperature excursion encountered in practice shows.

The formula for thermal expansion per metre is:
$\Delta L = l.\alpha.\Delta T$

Where:
L = 1000 mm.
$\alpha_{steel} = 12 \times 10^{-6}$
$\alpha_{aluminium} = 23 \times 10^{-6}$
$\Delta T = 40$ °C
$\Delta L_{steel} = 1000.12.10^{-6}.40 = 0.48$ mm
$\Delta L_{aluminium} = 1000.23.10^{-6}.40 = 0.96$ mm

As the strip remains straight during this temperature increase, compressive stresses must be absorbed by the aluminium and over the 40°C. It would be compressed by 0.96 - 0.48 = 0.48 mm per metre. Using the modulus of elasticity for aluminium (E) 0.7 .10^5 N/mm².
Hooke's law calculates the stress produced.

$$\sigma = \frac{E.\Delta l}{l} = \frac{0,7.10^5.0,48}{1000} = 33,6 \text{ N/mm}^2$$

In other words, a compressive stress of 33.6 N/mm_ is produced in the aluminium during a temperature change of 40 is produced in the aluminium during a temperature change of 40° C and this is totally acceptable for this material.

Inspection.

If the welded joints are to be inspected this is best achieved using the dye penetrant method. A practical existing procedure is MIL STD-271.
This method reveals surface defects like fissures, undercuts and laps which can be repaired later.
The procedure is as follows. A liquid with high capillary activity is introduced onto the surface. After a penetration time of about 20 minutes the surface of the area to be tested is wiped clean. After this a white powder (developer) is sprayed on the surface.
This white powder draws out any dye (usually red) which has penetrated defects by capillary action and these are then visible on the surface. This is a very sensitive technique as cracks of 0.02 mm width are indicated.
The length of the indication should be longer than 1 mm to count as a defect.
The indication does not give any information on the actual dimensions of the defect as the developed size on the surface is much greater.
The most commonly used method involves a washable liquid penetrant. Thus the surface to be tested must be completely dry and oil-free.
If weld-repairs are necessary, these areas should first be lightly ground with an abrasive tool before starting work.

Summary

Aluminium-steel transition joints produced by explosive bonding in air will show the undesirable, crack-initiating holes and oxide agglomerations as red indications when subjected to this dye-penetrant examination. This will not be the case in the vacuum clad product, Triplate.
These instructions (suggestions) are partly based on theory and partly on practical experience (empirical).
If in doubt, it is suggested to contact the experts at SMT in Schijf Holland.

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Fig 13: Temperature gradiënt during welding

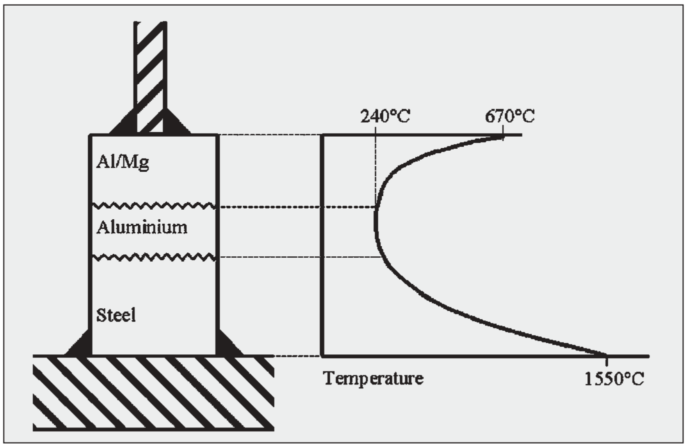

Fig 14: A butt weld joint avoids gaps between the ends of the transition strips