OTC 11063

Friction Welding - Technology for the New Millennium

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Abstract

This paper describes the process of friction stud welding and how it has been developed for use in the North Sea.
Attention is given to explaining why friction welding does not suffer the inherent problems associated with conventional welding techniques, (particularly when used underwater), how superior metallurgical integrity can be achieved, and how (unlike any other welding method) the process can be used at ANY water depth without any change to weld parameters or weld quality.

Following this, the paper describes the hyperbaric trials and then the work carried out in executing the deepest LIVE friction welding operation in the world to date. The work was carried out in 395 metres of water West of Shetland and involved the friction welding of anode continuity tails to riser base piles using a work-class ROV (Remotely Operated Vehicle).

The paper documents the work currently being carried out by a Consortium of European Companies funded by a European Community grant for the development of a friction welding system using a process known as Friction Stitch Welding and the associated deployment equipment to carry out crack repairs on vessels, platform structures, and pipelines.

Finally the paper outlines the proposed development to be carried out in extending the crack repair technology to enable the joining of pipe up to 42 inches outside diameter at extreme water depths.

In summary, with the constant search for resources in ever deeper water this technology will provide the Engineer with a reliable and cost effective method of joining materials at extreme depths for construction, repair, maintenance, salvage, corrosion protection and many other tasks. - TECHNOLOGY FOR THE NEW MILLENNIUM.

Introduction

The process of friction welding has been available for workshop use on a commercial basis since the 1950's.

It is used extensively in the automotive and aerospace industries because of its reliability, repeatability, weld integrity and ease of automation.

In 1983 the world's first "portable" equipment was built for use in the North sea and was used to great effect for making anode attachments at 150 metres water depth. This was documented and presented at previous OTC.[1]

Since then equipment has become truly portable, and the development of computer technology has provided the facility of much smaller and more accurate control/monitoring systems with in-process proof testing.[2]

Thus the equipment has now attained an extensive track-record for use both topside and underwater for repair, maintenance, construction and many other applications in the offshore, marine, defence, construction and nuclear industries.

Process Description

Friction welding is a "solid state" process that produces a weld under compressive forces applied to workpieces rotating or moving relative to each other. Local heating and the compressive forces result in plasticised material being displaced from the faying (rubbing) surfaces.

At a given point, motion ceases and the compressive forces are maintained or increased as the joint cools.

The weld exhibits a narrow HAZ (heat affected zone) with absence of fusion zone, and a weld flash of plastically deformed material.

No filler metals or fluxes are required thus avoiding weld-dilution and no shielding gas are used.

The absence of a of liquid weld pool prevents the possibility of gaseous diffusion into the weld metal, avoiding hydrogen enrichment, (and thus hydrogen cracking) and nitrogen enrichment.

Compressive forces in the weld zone produce a fine-grained forged weld which exhibits higher fracture toughness than the parent materials, as demonstrated in tensile tests which fail away from the weld zone.[3]

The process is self cleaning, and highly tolerant to surface contaminants which in an operational situation may save considerable time because weld area preparation is minimal or even eliminated.

No slag or fumes are produced making in-air use environmentally friendly. Weld porosity and inclusions are eliminated.

Welds produced underwater, even to high-tensile steels, exhibit the same integrity as those welded in air.[4]

In addition to this because friction welding is a purely mechanical process the weld parameters do not change with depth, eliminating the requirement to re-classify the welding process as depth increases.[5]

Particular Advantages

The process is easily automated to produce repeatable high quality welds without reliance on operator skill or intervention. Current equipment can be operated from up to 4 kilometers from the weld site making it particularly suitable for robotic applications in hazardous environments.

An extensive range of different material combinations can be welded, including exotic materials which may be difficult or even impossible to weld by conventional means. (e.g. titanium to stainless steel, and aluminium to ceramic).

The small heat input and fast cycle times allow welding to be carried out on live pipelines, gas-lines and methanol lines.

Friction stud welding has also been certified for use WITHIN explosive atmospheres to Zone 0 without risk of ignition. This allows welding to be carried out safely in Zoned areas of Offshore and Petrochemical Installations without recourse to shut-down of plant and equipment.

Metallurgical integrity allows welding to be carried out to primary steel structures and live pressure vessels without risk of cracking. The process has even been assessed successfully for the welding of attachments **directly** to the pressure hulls of Naval Submarines.[6]

Deepest Welds

The latest friction stud welding equipment is rated for working at 1000 metres of water depth. Although the welding process has been proven in a chamber at 700 metres, it was only in early 1998 that there was an opportunity to put theory to the test by carrying out welding at 395 metres water depth.

The Task

The studs were for anode continuity-tail attachments to the riser base piles of a platform west of Shetland belonging to one of the Major oil companies. Work was carried out in partnership with an ROV operator from one of their DSV's (Dive Support vessels) using a large work -class ROV.(Figure 1)

A tripartite weld configuration (Figure 2) was used, welding through a tapered hole in the centre of a "puck" attached to the end of the anode continuity cable.(Figure 3)

The Equipment

The friction welding equipment is a hydraulically driven friction stud welder capable of welding carbon steel studs up to 25mm diameter. It is electronically controlled, with machine functions displayed on a PC in real time.

The pressure-proof enclosures containing the electronics and AC/DC power converters were co-mounted with the pressure compensated hydraulic control-valve box in an aluminium chassis frame.

This frame, fitted with quick-release mountings, could be quickly mounted as a sub-chassis under the ROV.

Hydraulic and electrical connections took power from the ROV system while communications from the topside PC were routed through the ROV main umbilical.

The weld-head unit itself was built into a specially designed clamp which was mounted on a "landing-pad" at the front of the ROV sub-chassis.(Figure 4)

Excursion umbilical, hydraulic hoses and instrumentation cable between the control systems and the weld head were tied back to the side of the ROV with bungee cord to allow the clamp/head unit to be deployed using the ROV manipulator.

Proving Trials

Prior to mobilisation, trials were carried out in a water-filled hyperbaric chamber pressurised to the depth at which the equipment would be working offshore.

The aim of these trials was to prove the ability of the friction welding equipment to produce satisfactory welds at depth.

Weld samples done during these trials were sectioned and hardness surveys performed to prove metallurgical integrity. These results were then used to provide the weld procedures used during the Offshore Operations

Trials were also done in air onto a section of pile material using the specially designed clamping system. This was to prove the alignment, operation and integrity of the clamp and welding process.

The Client representative was present at all phase of trials. On completion of the trials the equipment was then fitted into the ROV skid and a buoyancy check done.

Offshore Operations

Continuity tails were first attached to the anode sledges, and tied off with cable-ties.(Figure 5)

Pucks were then filled with insulation material used to prevent quench hardening of the weld.

Once the DSV was on station over the pile, a survey ROV was deployed.

On completion of the survey an anode sledge was lowered to the seabed adjacent to the pile.

A dummy pile was then lowered to the seabed alongside the anode sledge to assist in loading the puck into the welding clamp.

Positioning of these was monitored using the ROV on-board camera system, so that it was possible to reach the puck, the dummy pile, and the pile with the manipulator.

After this, the ROV was landed on the seabed ready to start the welding phase.

First of all, the puck was picked from the anode sledge, breaking the cable tie.

The puck was then placed in the guide on the dummy pile, and latched so that it would not fall off.

Next, the friction welding clamp was lifted onto the dummy pile, and allowed to slide down into its own guide. This ensured that the puck was in alignment with the friction welding head.

By energising the hydraulic ram on the clamp, the friction welding head moved forward, picking up on the puck so that the stud was concentric with the hole in the base.

Reversing the hydraulic rams would then withdraw the friction welding unit, now with the puck in place.

The clamp could now be lifted off the dummy pile and placed over the actual pile where the weld was to be carried out.

This time when the hydraulic rams were energised, the friction welding head was advanced, with the puck in place. The puck was thus held against the pile with force sufficient to locate it securely throughout the weld.

Using the topside PC, pre-weld test routines were then carried out to check the functions of the friction welding equipment, and to establish the touch-down distance of the stud from the pile surface.

The friction weld was then initiated, with all functions displayed topside as the weld progressed.

No cleaning or grinding was done, and all welds were made through the existing paint coating on base piles.

After welding, the hydraulic rams were reversed, and the friction welding head retracted from the pile surface clear of the puck. The clamp could then be lifted off the pile and placed back on the carrier of the ROV.

The dummy pile was retrieved and the ROV then returned to the surface to be made ready to repeat the operation on the next location.

It is feasible to make a reloading system to avoid returning to surface, but under the circumstances, it was not deemed necessary for this particular job.

In terms of operational speed the round-trip surface-seabed and return was estimated to take $2^1/_2$ hours, and yet 5 welds were completed in one 15-hour period.

Friction Welding repair Techniques

Friction Hydro-Pillar Processing

This variation of friction welding, patented by the Welding Institute, may be described as a “drill and fill” process.

To execute the weld, a consumable rod is rotated and advanced coaxially into a circular cavity.(Figure 6)

As the rod bottoms out, frictional heating occurs resulting in metal flow along shear planes at the base of the rod.

Selection of the correct axial pressure and rotational speed induces the shear planes to move up the rod contacting the walls of the cavity. Frictional heating also takes place by the scouring action resulting in a bond forming between the wall and the rod material.

The integrity of this bond has been proven by cutting strip through the fill material (Figure 7) and subjecting the resulting rectangular piece to bend testing. Bend tests of 180 degrees are achieved, even using a plain carbon steel consumable into chrome molybdenum steel, without cracking or separation of the weld interface. (Figure 8)

The consumable rod undergoes significant hot-working resulting in a very refined heat treated microstructure. (Figure 9)

The microstructures shown in this figure are as follows:-

a - Parent base material
d - Parent consumable material
h - fusion line between consumable and base material
b - heat affected zone adjacent to fusion line
c - heat affected zone of base material
e - fine-grain forged material in transformation zone
f and g - fine-grain fully transformed material in FHPP fill.

This method of filling is also a SOLID PHASE process, thus, as stated earlier in this paper, avoiding all the problems associated with solidification of a liquid weld pool.

Friction Stitch Welding

Once the weld parameters have been developed for producing a hole-fill, it is a simple step by doing a continuous drill and fill operation to repair a crack or even join material together. (Figure 10)

This process has been termed Friction Stitch Welding.

Advantages of the process

- Solid phase joining process
- Deep penetration for repair or joining
- Ability to join large sections in a single pass
- Easily automated
- Environmentally friendly
- Operates underwater, explosive atmospheres and other hazardous areas.

State of the Art

A consortium of European Companies, funded by a European Community Grant are developing the process and equipment

to carry out the process of friction stitch welding.[7]
This project has now passed the mid-term milestone and is at a point where fills are now being made which are 9.5 mm diameter and 16 mm deep. This is not a limitation of the process, but a function of commercial equipment available. Each fill takes 4 seconds to weld.
At the time of writing, new equipment is being built which will extend the fill depth to 35 mm. It is also expected to extend the fill diameter greater than 12mm. This equipment will start trials in late March 1999.
Computer models (Figure 11) have been made to show methods of deployment and illustrate how the process will be operated.[8]

Technological Market

Initial development work has been concerned primarily for use in the Offshore, Marine, Defence and Nuclear industries.

There are over 7,000 offshore fixed steel tubular structures world wide, of which approximately 50% are over 20 years old, and many of these contain fatigue cracks.

In addition to this there are thousands of miles of pipeline vulnerable to damage, cracking, or requiring modification by tie in of new lines etc.

It is also foreseen that new lines will be required in water depths beyond the capacity of convention pipe-laying techniques. This will require joining techniques to be used which are capable of working at extreme depths enabling the welding to be carried out on the sea bed.

These are but a few of the areas where the process of Friction Welding will provide the means of achieving the objectives - TECHNOLOGY FOR THE NEW MILLENIUM.

Acknowledgements

Thanks to Dr Jorge dos Santos, Dipl-Ing D. Pauly and Dipl-Ing. A Meyer of GKSS Forschungszentrum for preparation of samples and photographs used in figures 8 and 9

Thanks to Dave Gibson, Project Manager Brite Euram Project BE96-3692 for figure 11.

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[2] Blakemore G.R., “Design and Implementation of a Total Control System for a Portable Friction Welding Machine”, paper 6, presented at the 4th International Conference “Computer Technology in Welding”, TWI, Cambridge, UK, 3 - 4 June 1992.

[3] Pauly D., Blakemore G.R., dos Santos J.F., Gibson D., “A Preliminary Study on the Application of Friction Welding in Structural Repairs” document GKSS 98/E/15, GKSS-, Forschungszentrum, Geestacht, Germany, 1998.

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[6] McGowan C.D., “Evaluation of the Hydro Marine Systems HMS3000 Friction Stud Welding Machine” Defence Research Agency report DRA/SMC/CR973005, Farnborough, January 1997

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[8]. Available on Internet Web Page www.gibo.demon.co.uk

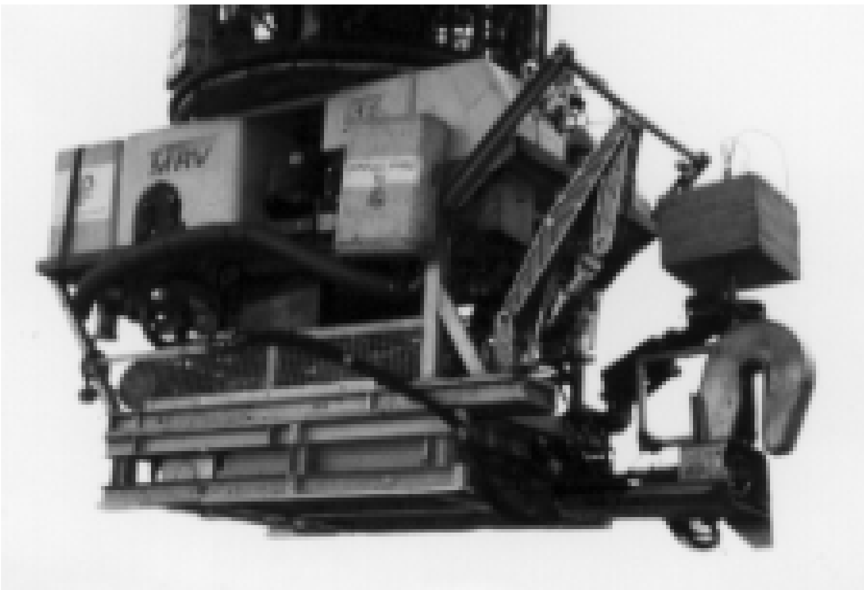

Figure 1 - ROV with Friction Welding Clamp

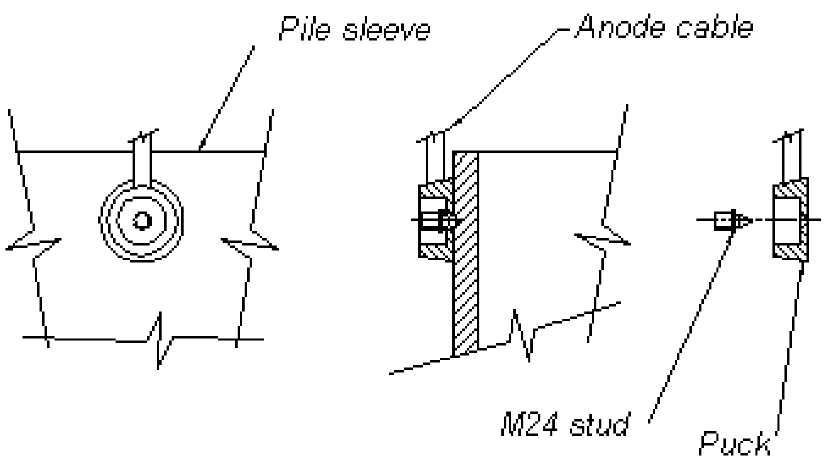

Figure 2 - Tripartite Weld

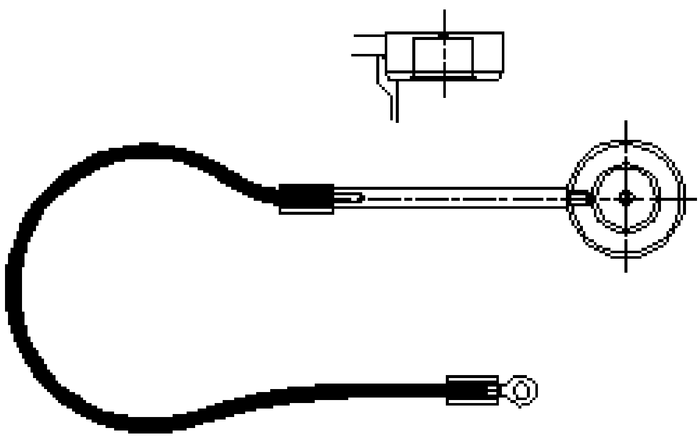

Figure 3 - Puck Assembly

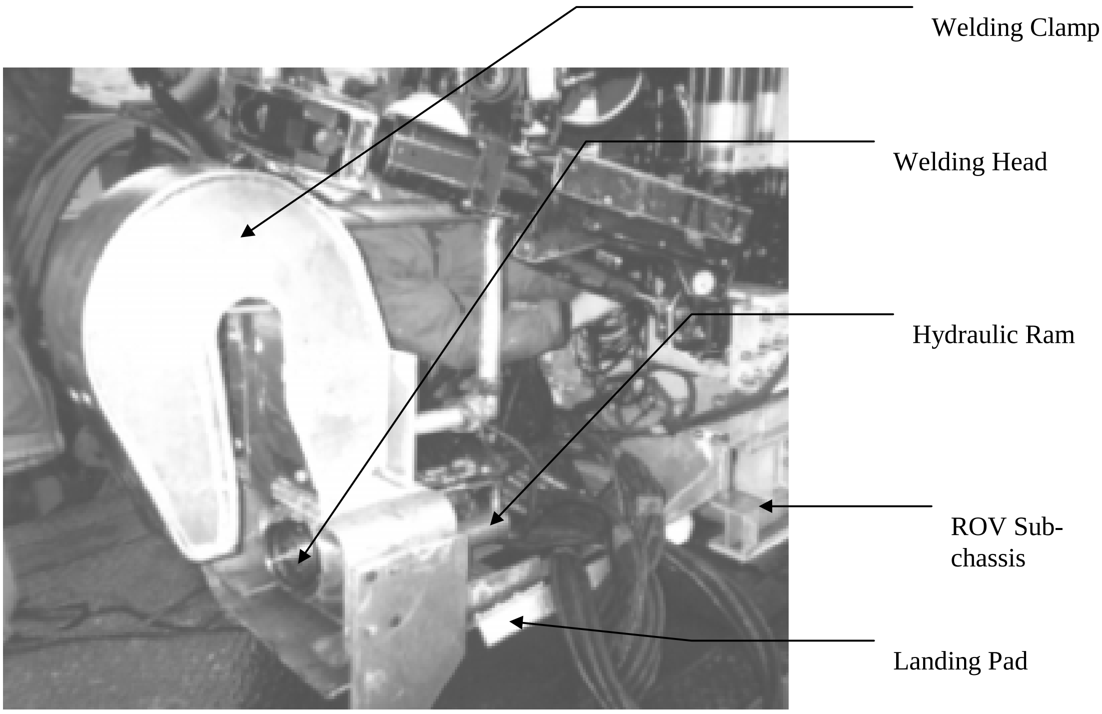

Figure 4 - ROV Sub-chassis and Welding Equipment

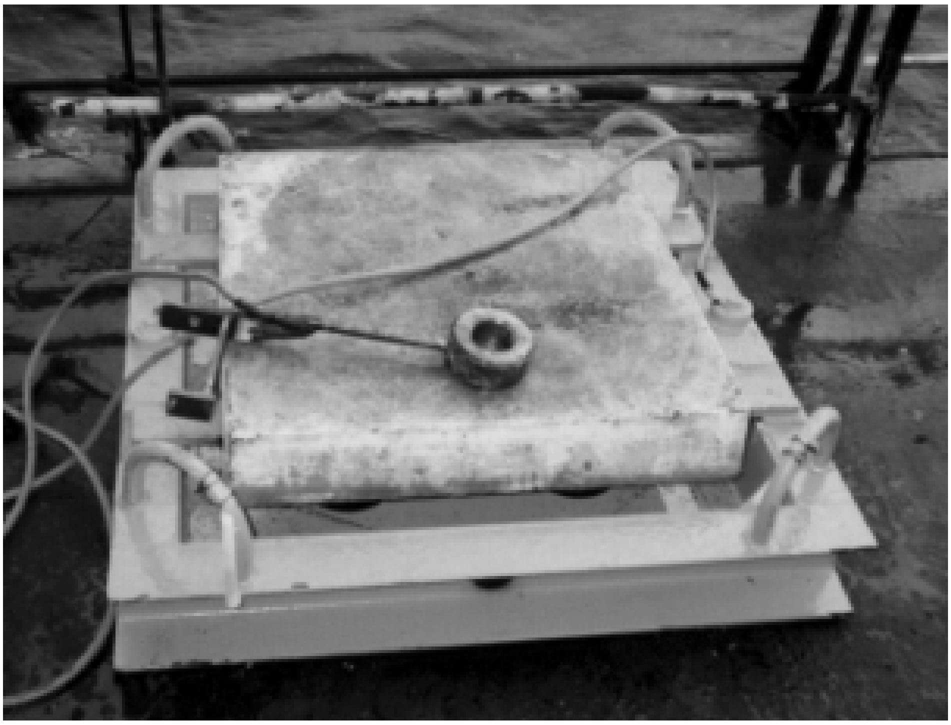

Figure 5 - Anode Sledge Assembly

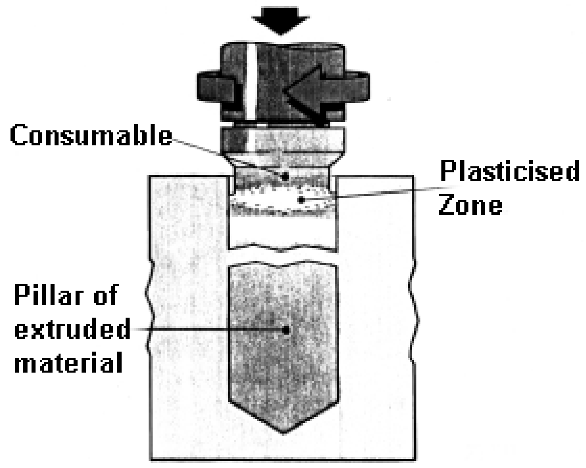

Figure 6 - Friction Hydro Pillar Process

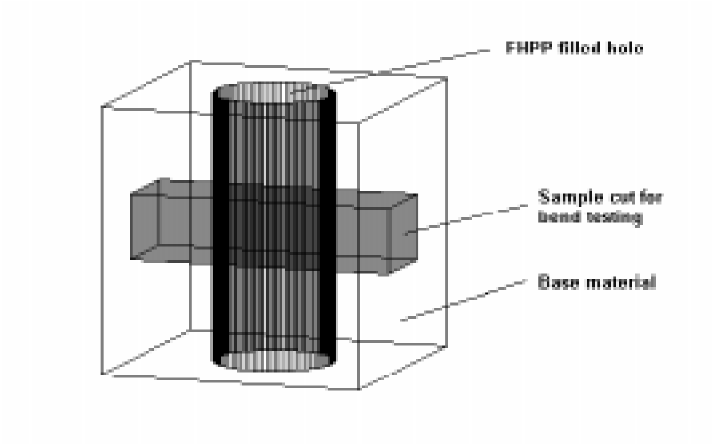

Figure 7 - Preparation of Bend Test Samples from FHPP Fill.

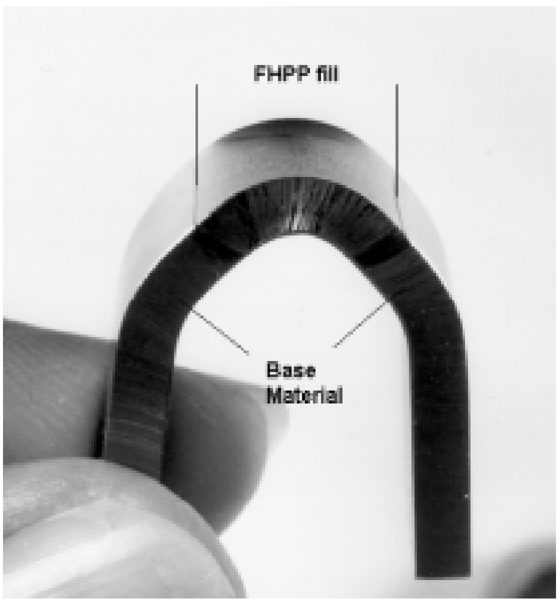

Figure 8 - Bend Test of FHPP Fill (carbon steel into chrome-molybdenum steel)

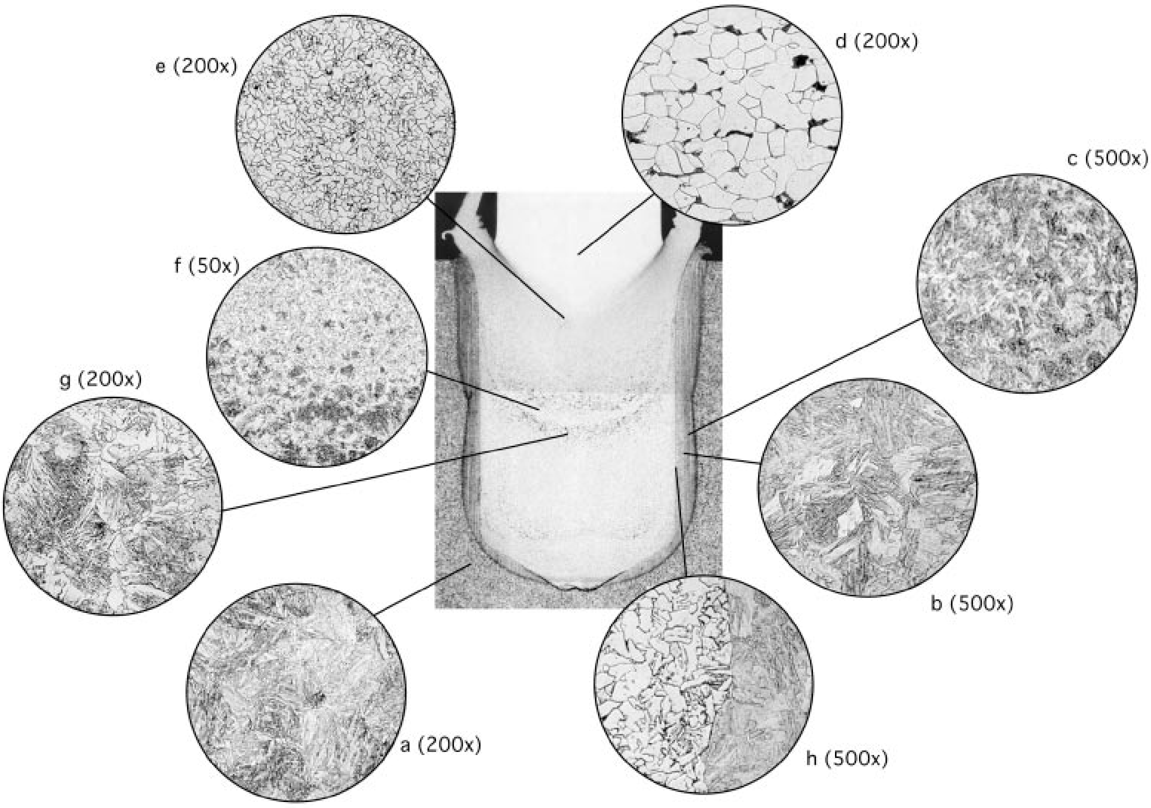

Figure 9 - Microstructure of FHPP Filled Hole

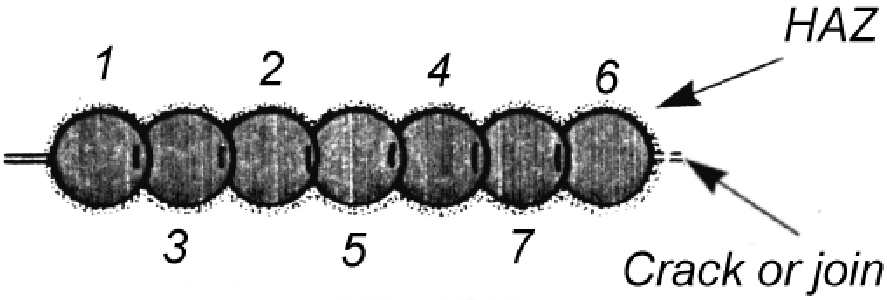

Figure 10 - Friction Stitch Weld

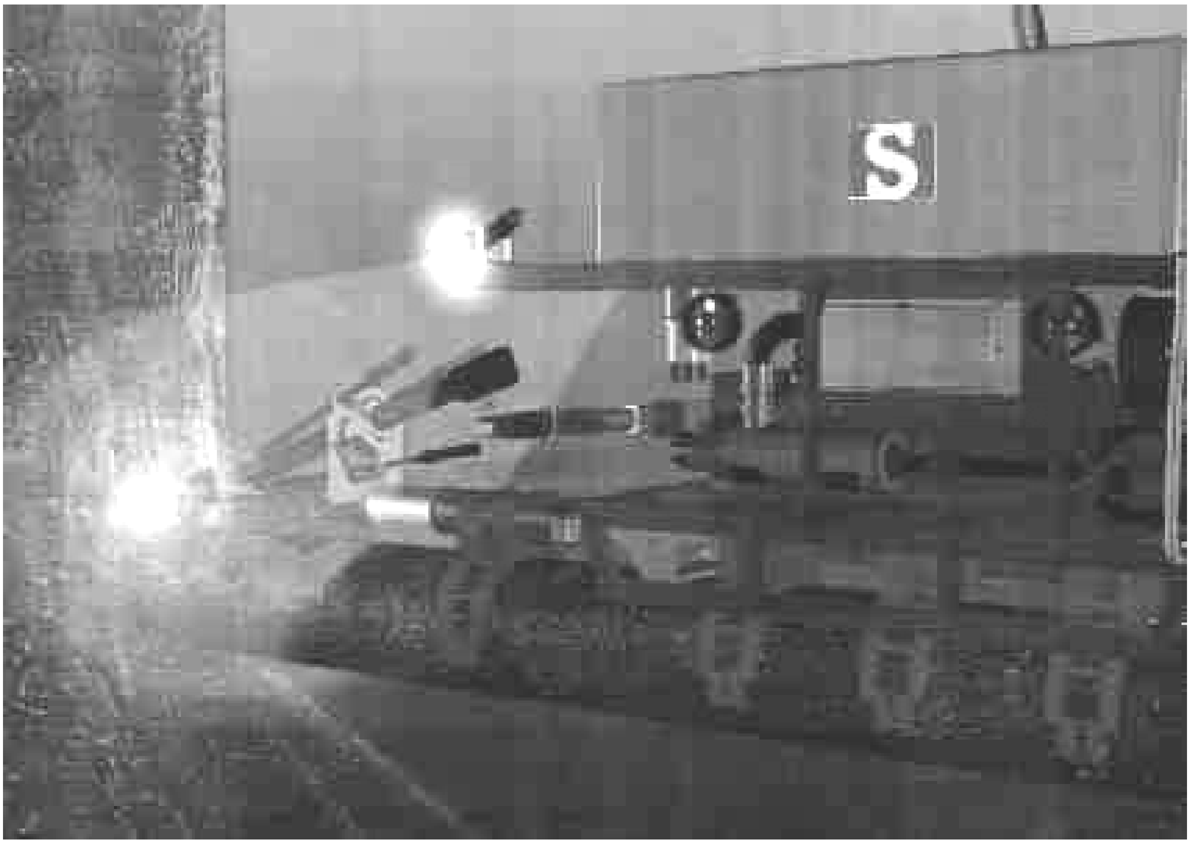

Figure 11 - Computer Graphic of Crack Repair using Friction Stitch Welding