# Technical Note: Preliminary Results on Underwater Laser Beam Welding of Steels

*Underwater welding with a laser shows some promise as an alternative to conventional shielded metal arc "wet" welding*

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An investigation is underway at The University of Aberdeen using a high-power carbon dioxide laser for direct underwater butt joint welding of steels to assess the quality of welds compared to in-air laser welds. This preliminary work forms part of a general study of the application of laser beam welding and cutting within the offshore oil and gas industry. To this end, the feasibility of laser beam welding in both direct "wet" conditions and in "dry" hyperbaric conditions is being explored. Considerable advantages may lie in the remote direct "wet" repair of pipelines and structural members in terms of convenience, low cost and freedom from diver intervention. The laser beam welding mechanism, being fundamentally different from arc welding processes, may be able to overcome the normal problems of weld embrittlement and porosity when "wet" welding is attempted.

Successful laser beam welding underwater was first reported by Sepold and Teske (Ref. 1) who accomplished a number of partially penetrating bead-on-plate welds on mild steel. Recent work by Dunn, *et al.* (Ref. 2), has investigated the penetration of laser beams through water and the depth of holes that can be drilled in acrylic. In the current work, our primary concern is with the butt joint welding of steel plate without a filler metal. This technical note provides a comparison of underwater and in-air weld characteristics for fully penetrating butt joint welds, and provides an insight into the propagation characteristics of a high-power beam in water. The effect of increasing water depth is also investigated.

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## Experimental Results

To establish a control, or bench mark, a series of welds were performed in air, using a 1.2-kW $CO_2$ laser (Laser Ecosse MFK) under optimal welding conditions on 2.5-mm-thick (1 in.) BS 4360-43A steel. Following this, a further series of welds was completed under identical conditions save that the samples were totally submersed in water at various depths from skin covering to 14 mm (0.6-in.). The physical appearances of typical in-air and in-water weld beads are shown in Fig. 1. The underwater weld performed under 1-mm (0.04-in.) water depth (Fig. 1A) exhibits a similar appearance in terms of size and microstructure to the in-air weld (Fig. 1B), although underfill in the cap and occasional porosity are present. The mechanical properties of the two welds are comparable — Table 1. It is interesting to note the microhardness values were also similar.

Figure 2A shows that weld depth is most affected by speed at greater water depths, between 18 to 60 mm/s, (0.71–2.4 in./s), with less effect at higher speeds. Comparing the welds performed under other depths of water shows that at shallow depths, up to 2 mm (0.08 in.), the weld penetration dimensions are unaffected, as shown in Fig. 2B. At approximately a 4 to 6 mm (0.16–0.24 in.) depth, a slight increase is observed. Thereafter, further increases in water depth produce a steady reduction in the penetration.

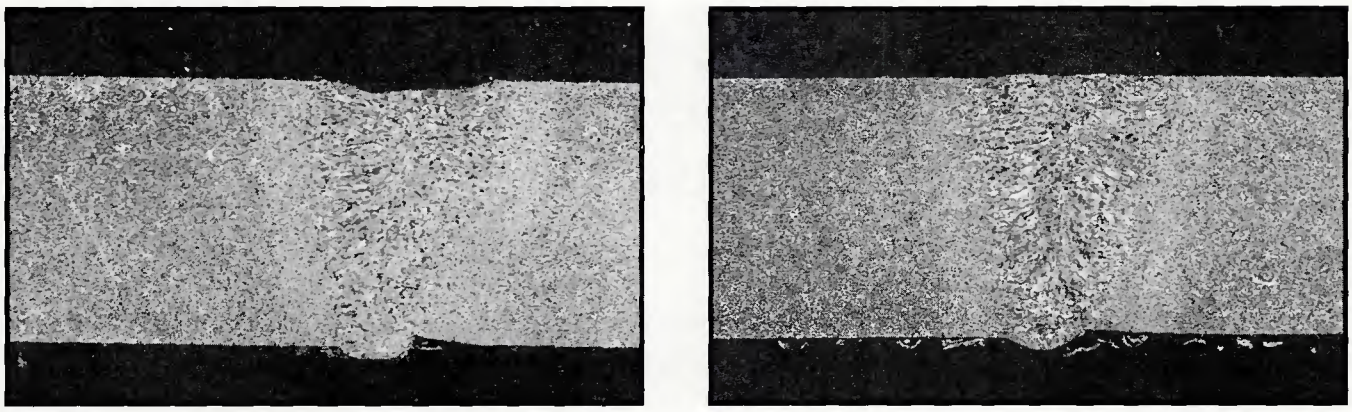
## Discussion

The achievement of high-quality welds obtained at depths of water up to 14 mm (0.6 in.) is an unexpected result (although recent results obtained by Dunn, *et al.*, Ref. 2, have spoken of the existence of a "beam propagation channel" through water when irradiated by high-power $CO_2$ laser radiation). The high irradiance of the laser beam ($>10^6$ W/cm$^2$) seems to produce a "wave guiding" effect in the water due to the vaporizing action of the beam, which produces a low attenuation corridor through the water. It is this which seems to allow the formation of deep penetration welds. Although there is the complication of absorption in the plasma and the heated workpiece, the beam attenuation is estimated using

$$E = E_o \exp(-\alpha d)$$

**Table 1 — Summary of the Weld Mechanical Properties**

| Metallurgical Test | In-Air Bench Mark Weld | Underwater Weld |
|---|---|---|
| Micro Hardness (HV) | Base metal 199 ± 8<br>Fusion 256 ± 18<br>HAZ 211 | Base metal 190 ± 6<br>Fusion 256 ± 30<br>HAZ 211 |
| Tensile (BS EN 10 002) | Failure in the base metal<br>Yield strength 270 kN/m$^2$ | Failure in the base metal<br>Yield strength 275 kN/m$^2$ |
| Sectioning | Sound microstructure | Cap underfill and spheroidal carbide formation |
| Radiography | Sound | Porosity (5%), with occasional underfill |



A B

*Fig. 1 — Micrographs of weld profiles for identical processing conditions (14X), with a laser power of 1.2 kW, traverse speed of 18 mm/s and a 100-mm focal length lens (Note: Slight vertical misalignment due to setup). A — Underwater weld; B — in-air weld.*

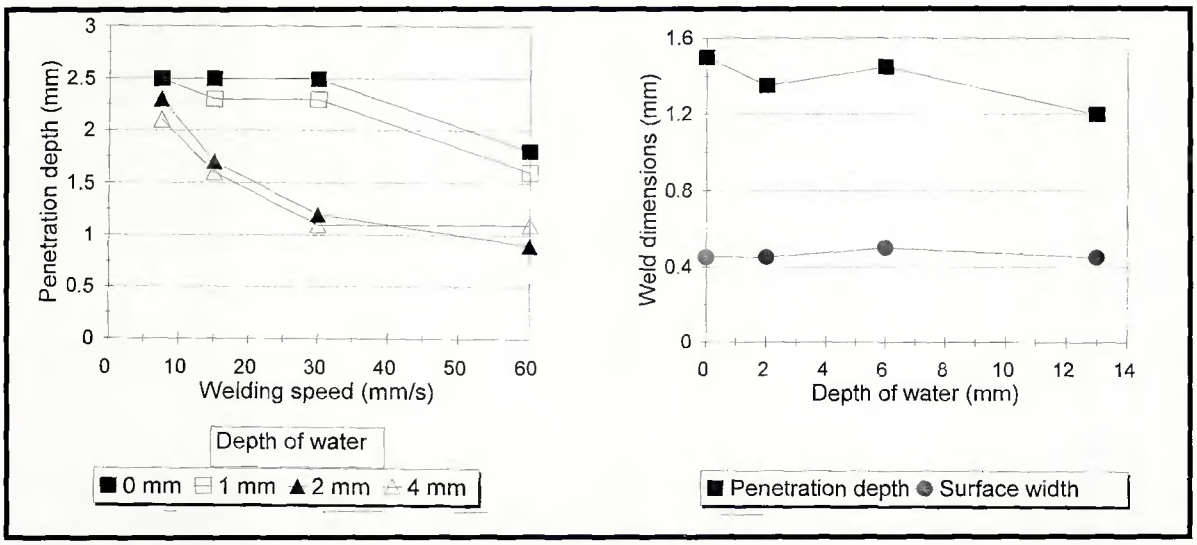



*Fig. 2 — A — Penetration depth vs. welding speed for different water depths; B — the effect of water depth on weld penetration for constant laser parameters. Note: 1.2 kW, 60 mm/s using a 100-mm focal length lens.*

to be around 1.5 $cm^{-1}$, based on an incident irradiance at the surface of the water of 1 .65 x $10^6$ W/$cm^2$ and a target surface irradiance of 9 x $10^5$ W/$cm^2$. This latter figure is the normally accepted value of irradiance, which must be attained if keyholing is to be obtained. The attenuation of the beam through water would seem to be minimal and this value for $\alpha$ should be compared with the normally quoted value of around 900 $cm^{-1}$ for absorption of 10.6 µm radiation in seawater (Ref. 3). Thus, it is evident that the laser beam may be able to propagate through considerable depths of water before the welding action is terminated.

The laser welding mechanism appears to show little difference between welding in-air or wet welding apart from a minimal irradiance attenuation. The majority of welds are mechanically sound, in both strength and hardness, although the welds over 10 mm (0.4 in.) depth contained porosity. The vaporizing action of the beam creates a beam corridor and adjacent steam/vapor annulus that seems to protect the weld from rapid quenching by the surrounding water. It is worth noting that comparable underwater shielded metal arc welds exhibit hardness values twice that of in-air welds. The apparent anomolous increase in penetration observed at certain depths may be the depth at which the waveguiding effect vs. the beam attenuation is optimal.

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