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# Cladding of High Mn Steel on Low C Steel by Explosive Welding

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**Abstract**

High Mn steel containing about 16% Mn was cladded to a low C steel by explosive welding. The experimental results showed that the bonding interface has a wavy morphology; the welding interface has the characteristics of both sharp transition and local melted zones between 2 metals. Hardness increased near the welding interface due to excess plastic deformation in the explosion area and phase transformation from $\gamma$ (f.c.c.) to $\alpha$ (b.c.c.).

**Key words:** Explosive welding, Cladding, High Mn steel, Low C steel.

## Introduction

Explosive welding is a solid-state process in which controlled explosion force is applied to join 2 or more metals at high pressures (Brasher and Butler, 1995). In this technique, energy produced by the explosive is used to accelerate a metal plate (flyer plate) across a predetermined distance (stand-off distance) to contact with another metal plate (base plate) as shown in Figure 1. Since no external heat is used to promote the bonding, this process is known as a "cold welding technique". High-localized temperatures are normally generated at the weld interface due to the dynamics of the process. The combination of the pressure, heat and flow can produce an interface bond having strength equal to or greater than that of the parent metal (Blazynski, 1983).

Austenitic Mn steel, known as Hadfield steel, is a tough, wear-resistant, nonmagnetic alloy usually containing 1.0 to 1.4% C and 10 to 14% Mn. It is available in cast and wrought form (ASM Handbook, 1989). High Mn steel can also be used as cladding material. Hadfield steel cladding can be produced by explosive welding, and laser and plasma spraying (Otto and Carpenter, 1972; Pelletier *et al.,* 1995).

The aim of this work was to examine the cladding behavior of a high Mn steel to a low C steel.

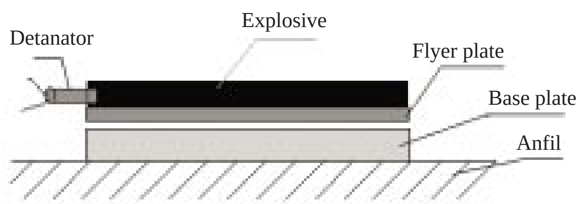



**Figure 1.** The parallel arrangement set-up explosive welding.

## Experimental Procedure

The high Mn steel used in this study was cast with dimensions of 250 x 250 x 45 mm after induction melting. Rectangular plates (125 x 45 mm) 3 mm thick were sliced from the cast ingots by erosion cutting. Low C steel was supplied as a plate 10 mm thick. The chemical compositions of the high Mn steel and low C steel used in this study are shown in Table 1.

**Table 1.** The chemical compositions of the high Mn steel and low C steel.

| | C | Mn | Ni | Cr | Si | Al |
|---|---|---|---|---|---|---|
| High Mn Steel | 1.45 | 15.9 | 0.32 | 1.45 | - | - |
| Low C Steel | 0.12 | 1.45 | 0.021 | 0.009 | 0.200 | 0.05 |

A parallel arrangement was used for the experimental set-up of explosive cladding, as shown schematically in Figure 1. The flyer plate and base plate were high Mn steel and low C steel, respectively. The explosive material, which was supplied by M.K.E. Barutsan Company, Turkey, was ELBAR-5 with 3200 m/s explosion velocity (ammonium nitrate 90%, min 4.5% fuel oil and min 3.0% TNT).

After explosive cladding, a metallographic examination of the sample was carried out using a Jeol JSM 5600 scanning electron microscope. The hardness of the cladded metal was measured with a Tucon LL model micro hardness testing machine. During the test, 50 g loads were applied to the indenter. X-ray diffraction experiments were carried out using a Shimadzu XRD-6000 with Co $K_\alpha$ radiation ($\lambda$ = 1.7902 A°).

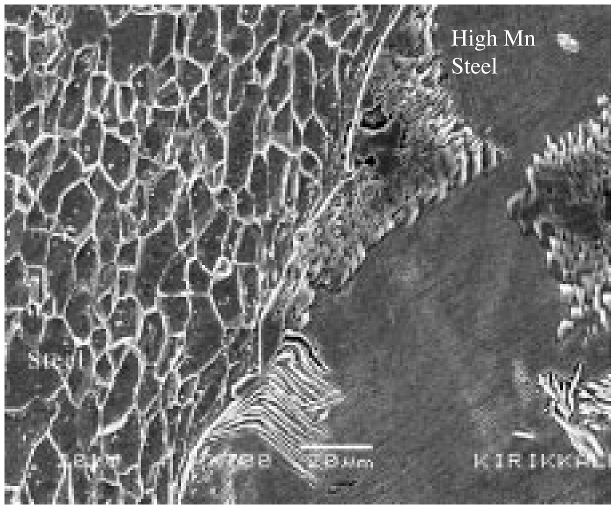



**Figure 2.** Welding interface of high Mn steel and low C steel.

## Results and Discussion

The experimental results showed that successful cladding of high Mn steel on low C steel was achieved by explosive welding (Figure 2). The welding interface has a wavy morphology, which is the typical morphology of explosive welding (Ezra, 1973; Crossland, 1976; Bahrani, 1967; Blazynski, 1983). However, some cracks in the outer side of the flyer plate, especially near the detonation region, have been observed. This could be due to excess plastic deformation of the high Mn steel.

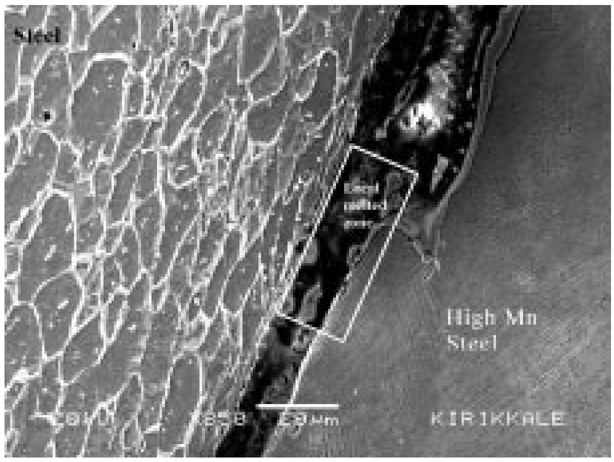
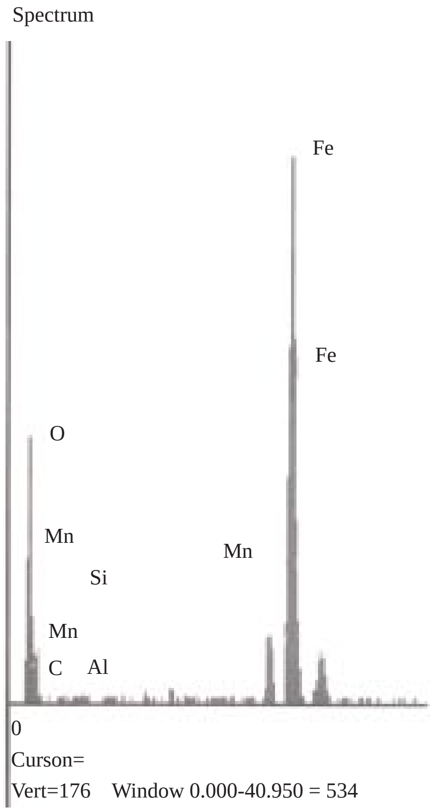



**Figure 3.** Local melting zone at the weldin interface.

During the SEM examination of some regions of the welding interface a local melting zone was observed (Figure 3). Crossland (1982) reported that the high kinetic energy in the jet will be dissipated as heat causing melting at the interface. EDX analysis (Figure 4) revealed that the composition of the local melting zone is different from that of the low C steel and high Mn steel. The presence of oxygen in this region can be attributed to the trapping of surface oxides during welding.

It has also been observed that the grains of the low C steel were elongated, especially near the welding interface (Figure 3). This may be due to deformation caused by the high velocity impact of the explosion.

Figure 5 shows the hardness profile of the welding interface. It is evident that the hardness of both materials increased. This is possibly due to the high plastic deformation that occurred at the interface during the explosion. These results are consistent with the early works of Johnson (1971), Ezra (1973), Truetnev (1973), and Richman *et al.,* (1995), who studied the explosive welding of NiCr alloy/NiCr alloy, 2014-T3 Al alloy/2014-T3 Al alloy, Al/Ti, Al/steel, Al/Ni and NiTi alloy/steel materials. The original hardnesses of the low C steel and high Mn steel were 150 Hv and 270 Hv, respectively. However, after the explosive welding, the hardness of the high Mn steel increased much more than the low C steel, which can be attributed to the high work hardening capacity of high Mn steel. Dastur and Leslie (1981) and Pelletier *et al.*, (1995) reported that the work hardenability of high Mn steel is higher than that of low C steel, which is in agreement with the present work.




| Elt | Line | Intensity (c/s) |
|---|---|---|
| O | Ka | 21.08 |
| Al | Ka | 0.37 |
| Si | Ka | 0.81 |
| Mn | Ka | 9.89 |
| Fe | Ka | 82.28 |

**Figure 4.** EDX analysis of local melting zone.

X-ray diffraction analysis of the high Mn steel given in Figure 6 revealed that austenitic phase (f.c.c.) transformed into a.b.c.c. phase after the explosion. However, the transformation was not completed since there are some austenite peaks in the X-ray diffraction spectrum. Pelletier *et al.,* (1995) investigated the effect of the deformation ratio on the phase transformation of Hadfield steel claddings produced by laser cladding. They concluded that a very high deformation ratio (50%) is needed to obtain complete transformation and reported the presence of a martensite phase in the claddings. In the present work, the formation of martensite in the cladding is most likely because at the weld interface the hardness of martensite was achieved.

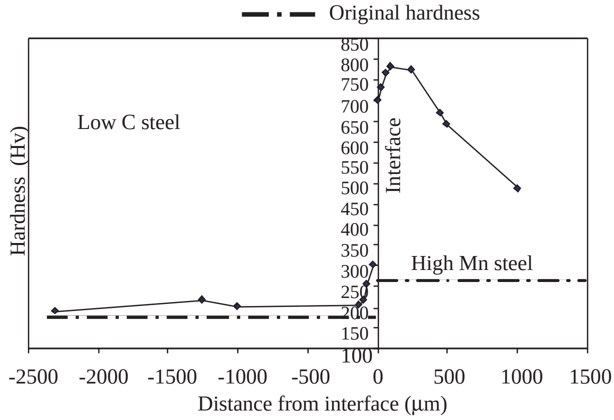



**Figure 5.** Distribution of hardness for low C steel and high Mn steel at the weld interface.

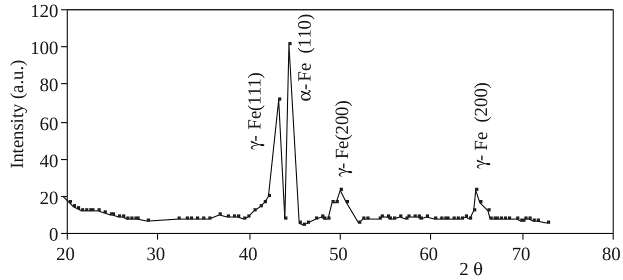



**Figure 6.** X-ray diffraction pattern of high Mn seel after explosive welding.

## Conclusion

The following conclusions can be drawn form the results of this study:

1. High Mn steel can be cladded to low C steel by explosive joining. At the welding interface a typical wavy morphology and localized melting zone are present. Grains of the low C steel were elongated near the weld interface.

2. The hardness of the high Mn steel and low C steel increased near the welding interface due to excess plastic deformation.
3. During explosive welding, FCC → BCC transformation occurred partially in the high Mn steel.

**Acknowledgement**

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