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Microstructural aspects of weld repair in 18 nickel 1800 MPa maraging steel

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The study of the microstructural aspects of the maraging steel weld repair has become important as this material finds extensive applications in aerospace and other strategic areas. The details available on these at present are very limited. During one of the fabrication trials of a large pressure vessel made of 18 Ni 1800 MPa maraging steel plates, 7.8 mm thick, defects were observed in the welds which were to be repaired. This called for simulated experiments. The microstructural variations observed in the repaired areas were the result of the repeated thermal cycles they had undergone. Based on this microstructural evidence, a new diagram depicting the newly formed weld zones is constructed from which the mechanical properties of the repair welds can be predicted.

1. Introduction

In a recent fabrication trial of a large pressure vessel made of maraging steel plates, 7.8 mm thick, in the aged condition, flaws which were beyond the acceptance limit were detected in the weldment, calling for the repair of these welds. Because data on weld repair in maraging steel pressure vessels in the aged condition were scant, a detailed study was undertaken to establish the microstructural variations and the resulting changes in the mechanical properties, due to repair. The results of metallographic investigations into repair weld zones are presented. A modified diagram depicting the various weld and heat-affected zones produced by repairing is presented.

2. Experimental procedure

Two 18 Ni 1800 MPa maraging steel plates, 7.8 mm thick, whose composition is given in Table I, were subjected to standard full ageing treatment by heating to 753 K for 180 min, after welding. Subsequently the weld pools were gouged in both the plates at certain locations for repair using optimized weld parameters. A second repair welding was also done on one of the plates after gouging out the first repair weld, to establish the effects of a double repair. Specimens were cut for metallographic studies from the repair-welded portions (Fig. 1). All microstructural analyses were done on re-aged specimens.

3. Microstructural observations

The microstructures of the steel in various welded and repair-welded conditions could be delineated by etching the polished specimens with 5% Nital. The original weld, termed the virgin weld, consisted of four different zones, namely the weld pool, the coarse-grained fusion zone, the solute-depleted light etched first heat-affected zone (HAZ I) and the dark etched second heat-affected zone (HAZ II) containing solute-rich martensite and a fine distribution of reverted austenite (Fig. 2) [1].

Microstructural changes effected during repair welding of the virgin weld were studied by optical microscopy and X-ray diffraction. Although no significant changes in the microstructures of single- and

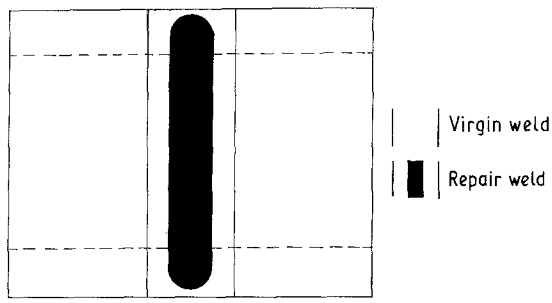

Figure 1 Schematic diagram showing the repair welded regions of the virgin weld in maraging steel.

TABLE I Chemical composition of maraging steel plate

Element	(Wt %)
Carbon	0.006
Manganese	0.032
Silicon	Not detected
Sulphur	0.002
Phosphorus	0.005
Nickel	18.12
Molybdenum	4.92
Cobalt	8.16
Titanium	0.49
Aluminium	0.11
Oxygen	7.0 p.p.m.
Nitrogen	9.4 p.p.m.
Hydrogen	0.9 p.p.m.

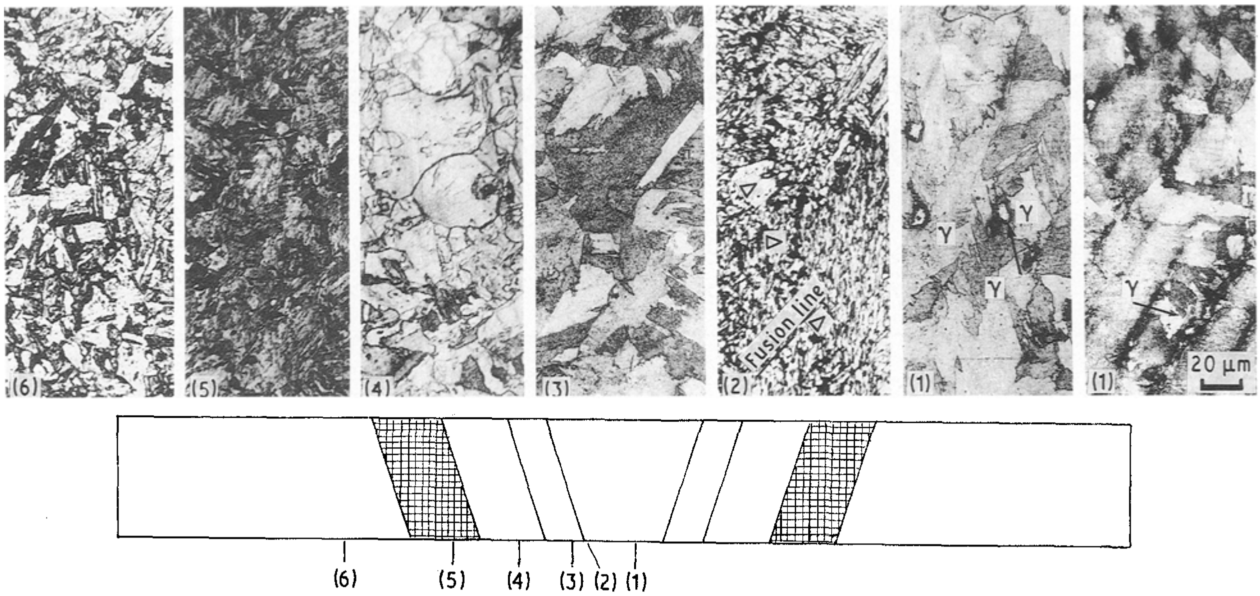

Figure 2 The weld pool and heat affected zones in maraging steel virgin weld. (1) weld pool, (2) fusion line, (3) coarse-grained zone, (4) HAZ I, (5) HAZ II, and (6) parent metal.

double-repair welded specimens were observed, there were noticeable changes in the microstructural features of the virgin weld and the repair welds. The microstructures of the virgin weld pool and its surroundings comprising the different heat-affected zones are shown in Fig. 2. A schematic presentation of the microstructural zones of the virgin weld and those of the new zones where salient changes in the microstructure were observed on repair welding, is presented in Fig. 3.

A metallographic traverse across the repair weld clearly delineated the gradual change in the microstructures from the repair weld pool to the parent metal. Fig. 4a–h are the typical micrographs from the regions marked in Fig. 3. It can be seen that the repaired weld pool had equiaxed grains with minute specks of uniformly distributed austenite (Fig. 4a). This was in contrast to the dendritic structures with some austenitic films in the interdendritic boundaries, in the virgin weld (Fig. 2.). The origin of dendritic arms, at the fusion boundary of the repaired pool, is evident from Fig. 4b. Considerable change in the microstructures of the original weld pool, which had not been gouged out, resulted from imposition of high-temperature thermal cycles. The partially recrystallized structures in Fig. 4c and the enlarged grains in Fig. 4d resulted from the variations in the thermal conditions.

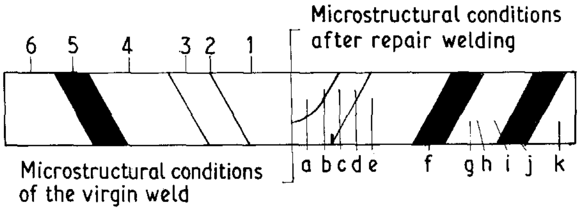

Figure 3 Schematic view of the various zones depicting the salient microstructural changes in repair welding. 1, Virgin weld pool; 2, fusion line; 3, coarse-grained zone; 4, HAZ I; 5, HAZ II; 6, parent metal. (a) Equiaxed grains in repair weld pool, (b) origin of dendritic arms, (c) partially recrystallized grains, (d) overgrown grains, (e) refined grains, (f,j) dark etched zones, (g,i) light etched regions, (h) unetched region, and (k) parent metal.

It was observed in Fig. 2 that a coarse dendritic structure existed on the side of the fusion line facing the virgin weld, while coarse grains were seen on its other side. Both these coarse structures were refined during repair weld, resulting in a microstructure consisting of fine grains (Fig. 4e).

On moving further away from the fusion line of the virgin weld to its HAZ I, it was observed that this region turned darker on etching after repair welding (Fig. 4f). The microstructural features of this area were similar to those observed at the dark etched second heat-affected zone (HAZ II) of the virgin weld (Fig. 2). Adjacent to this dark etched region was an area that was not affected by the etchant used. Beyond it lay another dark etched region. Thus an almost unetched region was found to be sandwiched between the two dark etching regions. The transition from the first dark etched region to the second was gradual, passing through a light region, an unetched region (Fig. 4g), and a second light etched region. X-ray diffraction analysis of the unetched region (Fig. 5) showed an austenite, γ, content of 12%–13% which was measured by comparing the integrated intensities of (1 1 1) austenite and (1 1 0) martensite, α, peaks. Extending beyond the second dark etched region was the parent metal (Fig. 4h).

4. Microhardness traverse

A microhardness traverse measured across the virgin weld after ageing and across the repair weld before and after full ageing, clearly delineated the different zones of repair welding. Table II gives the average microhardness values (VPN 100 g load) on each zone.

5. Discussion

Repair welding in maraging steel was found to refine the microstructures in the various zones of the virgin weld due to additional heat input and increased number of thermal cycles in the martensite–austenite

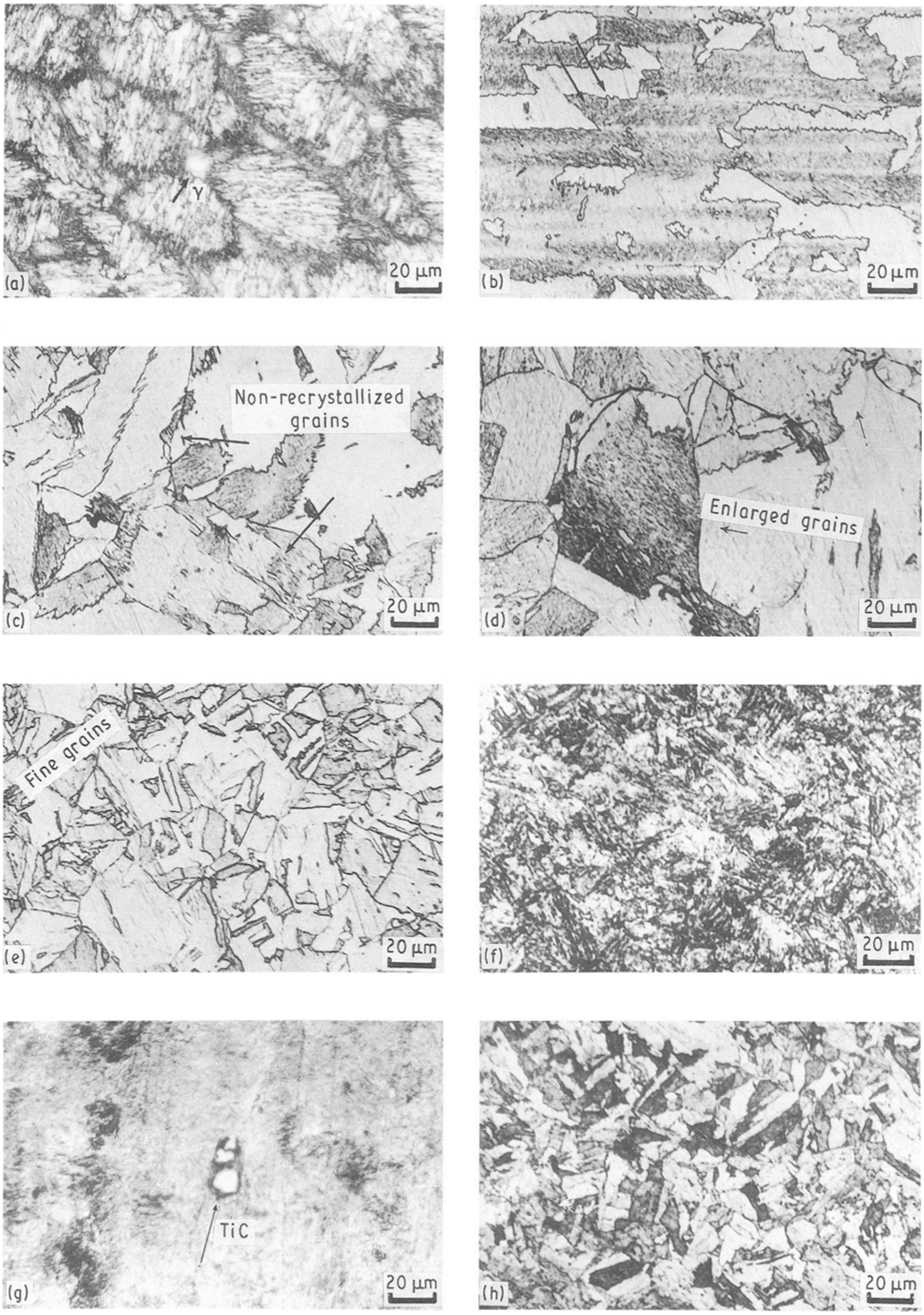

Figure 4 Microstructures at various zones after repair welding.

($\alpha + \gamma$) two-phase region. The repair weld pool, which was much smaller than the virgin weld pool, contained almost fine equiaxed grains (Fig. 4a). Examination of the microstructure revealed that the austenite, γ, content was low and it was distributed as fine specks, not as an interdendritic network. It appeared that the small weld pool was heavily constrained and the heat extraction by the surrounding material was quite

TABLE II Microhardness at the various zones in the Virgin weld and in the repair weld (see Fig. 3)

Zone	Virgin weld	VPN/100 g	Repair weld	VPN/100 g
Weld pool	1	540	a	548
Fusion zone	2–3	540	b–d	548
Fine-grained HAZ I	4	542	e	550
Dark etched region I	Not present		f	460
Light etched region I	Not present		g	450
Unetched region	Not present		h	390
Light etched region II	Not present		i	430
Dark etched region II	5	452	j	525
Parent metal	6	560	k	556

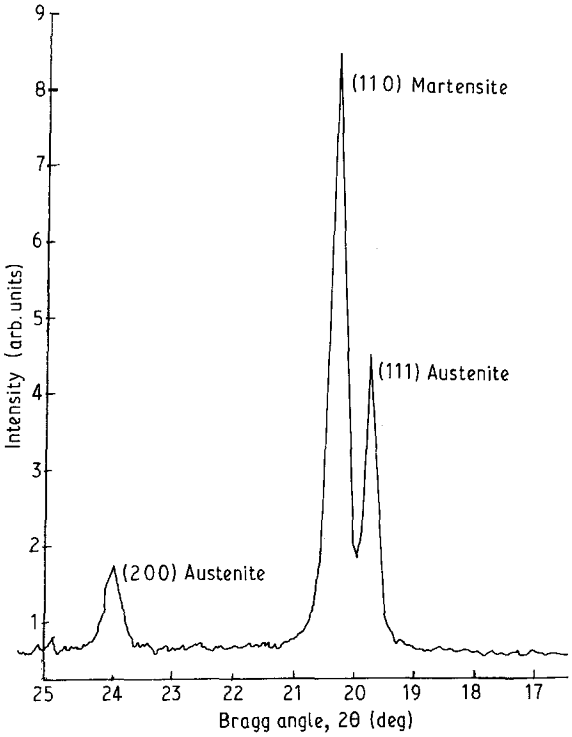

Figure 5 X-ray diffraction pattern of the "unetched" region (radiation MoK_{α}, 35 kV, 20 mA).

effective. The combined effect of these two factors gave rise to a sound microstructure in the weld pool, which would exhibit improved mechanical properties including fracture toughness. The additional heat input during repair, completely refined the virgin weld structure. The most striking changes from the normal welded structures of maraging steels was the appearance of two dark etched regions and an unetched region in between them, having an austenite, γ, content of 12%–13% in the repair-welded specimen. The virgin weld contained only one HAZ I followed by a dark etched HAZ II. The appearance of the first dark etched region (Fig. 4f) on repair welding could be explained on the basis of overlapping of the HAZ I of the repair weld on the pre-existing HAZ I of the virgin weld. The second dark etched region observed in the repair-welded specimen was the one which was already present in it after the virgin weld. Non-etching of the mid region between these two, was due to the presence of reverted austenite as reflected by the X-ray diffraction (Fig. 5) and microhardness data. The reversion to austenite, γ, was primarily caused by the partial superimposition of the edges of the HAZ II of the repair weld and that of the virgin weld. During the multipass repair scheme, this region experienced a condition of thermal cycling in the duplex $\alpha + \gamma$ region. It is known [2, 3] that increased cycling in this region stabilizes the reverted austenite. The solid state diffusion-controlled decomposition of the martensite during heating has been reported [4] to proceed according to

$$\alpha \rightarrow \alpha' + \gamma' \quad (1)$$

where α' is the alloy-depleted martensite, and γ' the alloy-rich stable austenite which does not transform to martensite during subsequent cooling. Because the initial weld was in the aged condition, the heat input during repair welding caused overlapping of the two second heat-affected zones in the $\alpha + \gamma$ region. This resulted in the overageing of this region where more iron–molybdenum compounds formed, as reported earlier [5], instead of the precipitation-hardened nickel-bearing compounds. This enriched the matrix with nickel which led to the stabilization of austenite.

Based on the above observations and discussions, a modified diagram depicting the various zones on repair welding was constructed (Fig. 3). Because the technological properties of a repair-welded maraging steel will depend upon the micro-constituents of the newly formed weld zones, it is expected that this diagram will be of great help in understanding the mechanical behaviour of the repaired structures.

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