In-situ Crack Repair by Laser Cladding

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Abstract

Laser cladding crack repair of austenitic stainless steel vessels subjected to internal water pressure was evaluated. The purpose of this investigation was to develop process parameters for in-situ repair of through-wall cracks in components or vessels which contain water under pressures of up to 2 bar. Successful crack sealing of 4.5 mm and 6.0 mm plate thickness @ 2.0 bar water pressure was achieved under worst case conditions. Positional cladding trials were also performed for 4 mm bead width at various cladding positions. Calculated powder efficiencies ranged between 87 and 93 percent.

Keywords: laser cladding, crack repair, austenitic stainless steel

1 Introduction

Stress corrosion cracking of austenitic stainless steel typically does not occur under atmospheric conditions. Some cases of SCC of austenitic stainless steel in chloride environments under atmospheric conditions have been identified and the influence of relative humidity, temperature, surface condition and corrosion properties on SCC have been investigated [1]. The aim of this investigation is to determine if in-situ stress corrosion crack sealing by laser cladding onto austenitic stainless plate material, under internal water pressure of 2 bar, can be performed successfully. The acceptance criteria were defined as no leakage after completion of the clad area. Clad area width of 10 mm was determined from previous experiments where widths of more than 10 mm resulted in excessive leakage in the seam area at the clad front. After crack sealing is achieved, an overlay layer of typically 1 mm thickness is cladded for improved pitting corrosion resistance. Crack sealing is considered to be a temporary repair technique.

In-situ repair requires that the equipment should be mobile for on-site repair. The IPG fibre laser was the laser of choice after careful consideration of all available laser sources. Initial experiments were performed with an Nd:YAG laser and articulated arm robot.

2 Experimental procedure

2.1 Crack sealing

Baseline parameters were determined for 4.5 and 6.0 mm 304L plates. Cladding parameters for a 2 mm bead width were developed for crack sealing. A leaking crack was simulated by using a flange, manufactured from two halves, bolted onto a pressurised tank under 2 bar water pressure. The faces of the two flange halves were machined and laser butt welded with three stitch welds. Shown in **Table 1** are the typical process parameters for the 2 mm bead width clad layer. A three-way coaxial cladding nozzle with 12 mm standoff and Rofin DY044 diode pumped Nd:YAG laser with a 300 mm focal length lens were used. The required spot size was obtained by defocusing 20 mm. Shown in **Figure 1** is the typical setup. Hammer peening of the simulated crack was performed prior to the cladding process to avoid water squirting out. Tests were performed in the vertical up and horizontal positions. Process parameters obtained were repeated with a 3kW IPG fibre laser and a Precitec YC50 cladding head retrofitted with athree-way cladding nozzle supplied by the Fraunhofer Institute for Laser Technology. Minor modifications of process parameters had to be implemented to obtain acceptable crack sealing.

Table 1: Typical process parameters for crack sealing

Material	***Power (kW)***	***Speed (m/min)***	***Powder feed rate (g/min)***
316L	1-1.5	0.6-1.2	5-12

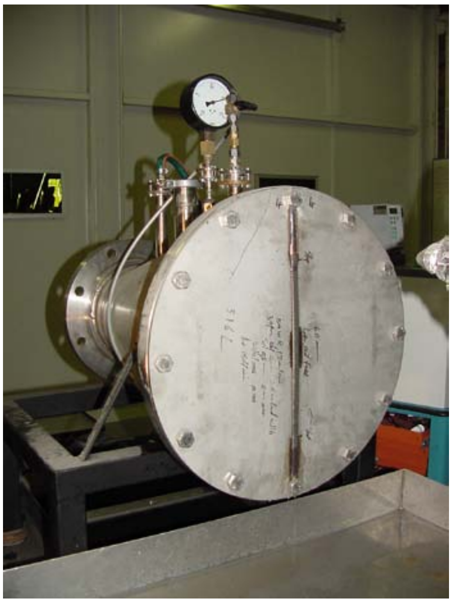

Figure 2: Setup of pressurised vessel.

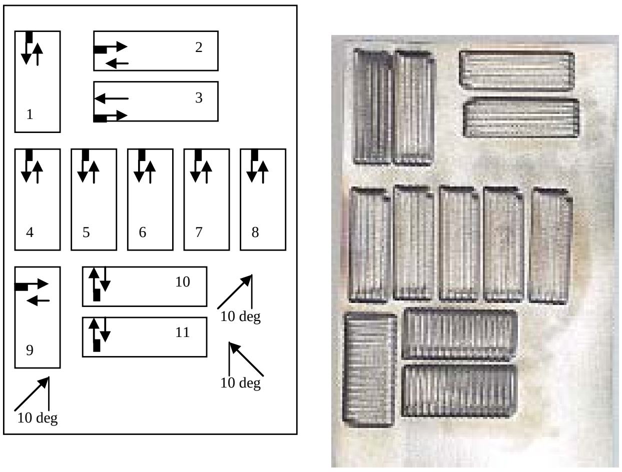

Figure 1: Overlay positional welding.

2.2 Overlay cladding

Overlay cladding of the sealed cracks is required to improve pitting corrosion and resistance to stress corrosion cracking of the crack-repaired areas. Cladding trials were performed to determine the effect of cladding position, nozzle standoff and angle between work piece and laser beam on powder efficiency for overlay cladding. Cladding trials were performed with a defocus distance of 40 mm to obtain a 4 mm bead width. These parameters were selected to maximise deposition rate and powder efficiency and will be applied over the crack sealing layers performed with a 2 mm bead width. A coaxial nozzle with 12 mm standoff and Ar carrying gas was used to deposit a weld overlay with Inconel 625 powder. Shown in **Table 2** is the cladding parameters used for the determination of powder efficiency for the various cladding positions as shown in **Figure 2**.

Material	*Power (kW)*	*Speed (m/min)*	*Powder feed rate (g/min)*
In 625	2-2.5	0.6-1.2	15-30

Table 2: Typical process parameters for weld overlay

3 Results and discussion

3.1 Crack sealing visual evaluation

The ability of laser cladding to seal leaking cracks is highly dependent on the simulated crack geometry. In some areas where water was squirting out strongly, cracks could be sealed in one pass. In other areas the water flow was too strong to cover the crack in a single pass. Cracks that could not be sealed after the first pass tend to create leaking pores which become even more difficult to seal in subsequent passes as shown in **Figure 3**.

These larger pores create a cavity in which water is trapped. Upon passing over the pore with the laser beam, rapid heating of the water takes place resulting in expanding steam which causes the formation of an even larger pore and is accompanied by expulsion of metal and subsequent cover slide damage.

Figure 3: Crack sealing without peening prior to cladding.

Hammer peening was introduced in order to mechanically seal of squirting water prior to crack sealing. Leaks were reduced from squirting to oozing. During cladding, water started squirting out again resulting in pore formation in some areas. Hammer peening of pores that occurred in the first layer enabled successful crack sealing after two layers.

Shown in **Figures 4 and 5** are the crack seal layers for 4.5 and 6.0 mm flange thickness respectively. Crack sealing with hammer peening prior to the first layer could be achieved for both the 4.5 and 6.0 mm flange thicknesses at 2 bar pressure after two layers.

Figure 6: Crack sealing of 4.5 mm plate @ 2 bar pressure.

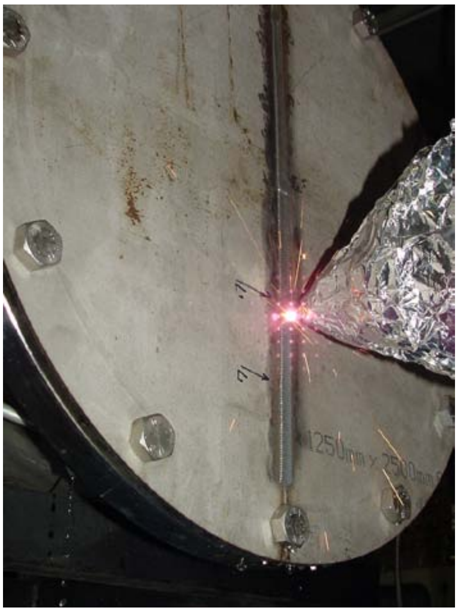

Figure 4: Crack sealing of a 6.0 mm plate @ 2 bar pressure.

Simulated crack repair and overlay cladding with 316L is shown in **Figure 6**. Three small leaking pores were observed in the first layer, indicated by arrows. Hammer peening was applied to the first layer to mechanically seal the leaking pores prior to deposition of the second sealing layer. Successful crack sealing was achieved after the second layer. A third buffer layer was applied prior to the single overlay layer. Crack sealing and overlay cladding were applied under internal water pressure of 2 bar.

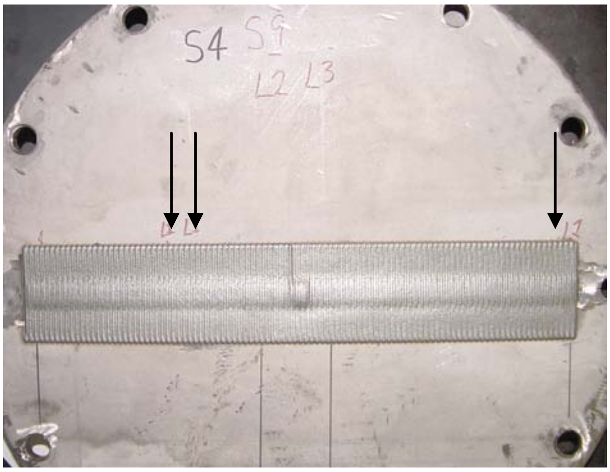

Figure 5: Crack sealing and overlay of 6.0 mm plate.

Successful sealing of simulated cracks was achieved under extreme conditions. Not only was water squirting out occasionally, but water was continually running down the peened crack to the weld pool. Laser cladding was shown to be a robust process under such harsh conditions. The initial process instability resulting in violent metal expulsion from the weld pool, large pore formation, excessive leakage and cover slide damage was expected. Through the optimization of the crack sealing process parameters, a stable repair process was developed. No cover slide damage occurred with optimum process parameters. Small leaking pores were observed in the first layer with no noticeable process instability during cladding in those particular areas.

3.2 Macro evaluation

Shown in **Figure 7** is a cross section macrograph of a simulated crack in a 6.0 mm plate, which was sealed under 2 bar internal water pressure. Two crack seal layers of 316L were applied onto the 304L test plate. Hammer peening was applied to the simulated crack prior to the cladding of the first layer to avoid excessive water squirting out. Adequate laser power is required to ensure proper fusion into the base material due to water squirting out of the crack adjacent to the weld pool. As a result of the higher laser power, the degree of dilution is fairly high.

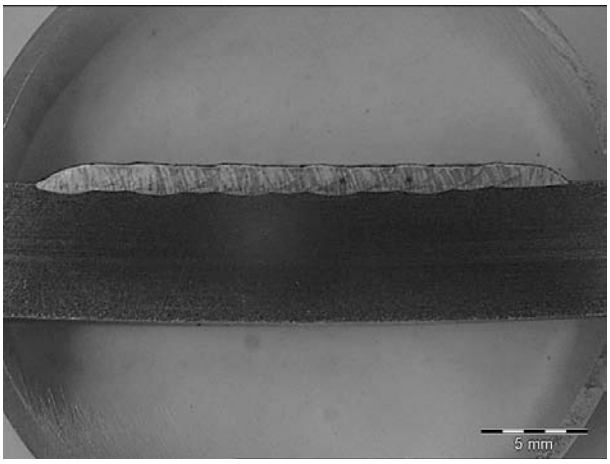

Figure 7: Cross section of single layer overlay, 6.0 mm thickness.

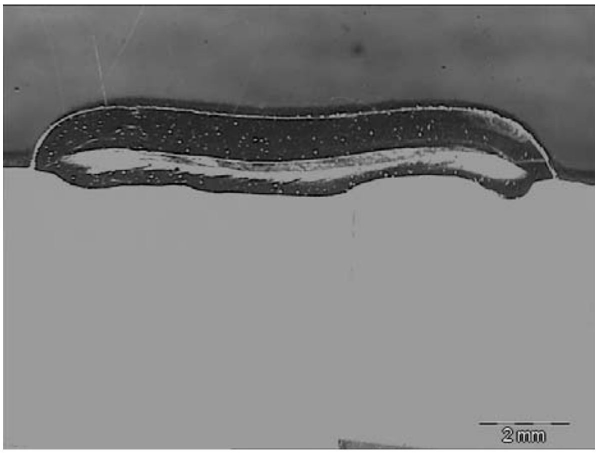

Figure 8: Cross section of crack seal, 6.0 mm thickness.

The typical hardness of the 316L crack seal layers is 160 HV_{1kg}. Crack sealing can be performed with more noble Ni-base alloys to improve resistance to propagation of stress corrosion cracks through the repaired area.

A cross section of the 316L overlay is shown in **Figure 8**. The calculated dilution of the overlay layer is typically less than 5 percent. As discussed previously, the overlay is required to improve the resistance of the sealed crack areas against stress corrosion cracking. Stress corrosion cracking can however occur in the weld toe areas of the overlay layer. Peening of these areas will be beneficial, since the introduction of surface compressive stresses will avoid the initiation of SCC.

Due to primary austenitic solidification of laser-cladded 316L, little delta ferrite is present in the microstructure. Although the susceptibility to solidification cracking is moderate, no cracking was observed during crack sealing and overlay cladding experiments.

3.3 Powder efficiency for overlay cladding

Inconel 625 (TAFA 1265F) powder was used to compare previous results obtained with 316L powder. A powder feed rate of 1.495 kg/h was used. Powder efficiencies obtained for the various positions are shown in **Table 3**. In previous experiments performed at the NLC, powder efficiency of 93 percent was obtained for 316L powder with a powder feed rate of 1.46 kg/h and an effective deposition rate of 1.37 kg/h, 4 mm bead width, 1.2 m/min, 2 500W, coaxial nozzle.

Table 3: Powder efficiencies, 4 mm bead width

Sample number	*Nozzle standoff (mm)*	*Powder efficiency (%)*
1	12	90.9
2	12	93.0
3	12	90.1
4	10	88.6
5	11	90.1
6	12	92.5
7	13	90.1
8	14	87.0
9	12	90.5
10	12	88.7
11	12	89.3

Samples 1 to 3 considered the influence of cladding direction: vertical versus horizontal top-down and horizontal bottom-up cladding. Samples 4 to 8 considered the influence of nozzle distance variation to the work piece from 10 mm standoff for Sample 4 to 14 mm for Sample 8, with an incremental increase in standoff of 1 mm. Sample 6 is at the optimum position with 12 mm standoff. Samples 9-11 considered the influence of the angle of the laser beam with the work piece.

Powder efficiency for the various positions ranged between 87 and 93 percent. Powder efficiency was calculated as the difference in mass before and after cladding of each position, divided by the powder feed mass. As shown in **Tab,le 3**, the nozzle standoff distance should be controlled within +- 1.0 mm to obtain powder efficiencies higher than 90 percent. The angle of 10 degrees to the normal was chosen as the worst case scenario for a three-axis gantry manipulation system that could typically be used to repair pipes or water storage vessels.

Powder efficiency should ideally be as high as possible and effective deposition rate should be maximised. Increased cladding speed and powder feed rate slightly reduce powder efficiency but increase deposition rate. The powder efficiency of 90 percent resulted in an acceptable effective deposition rate of 1.35 kg/h.

4 Conclusion

Successful laser cladding crack sealing of simulated cracks was achieved for test plates of 4.5 and 6.0 mm under extreme conditions.

Cladding trials were also performed for 4 mm bead width at various cladding positions. Powder efficiencies calculated ranged between 87 and 93 percent. Nozzle standoff should be controlled within +- 1.0 mm to achieve powder efficiency in excess of 90 percent.

5 References

[1] Fairweather, N.D., Platts, N., Rice, D.R., 2008. Stress-corrosion crack initiation of type 304 stainless steel in atmospheric environments containing chloride: Influence of surface condition, relative humidity, temperature and thermal sensitization. NACE Corrosion Conference, 2008.