

LASER CLADDING OF HIGH STRENGTH ALUMINIUM ALLOY 7075 POWDER ON A 7075 SUBSTRATE FOR REPAIR OF DAMAGED COMPONENTS

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ABSTRACT

Laser cladding is a surface engineering technique that has been employed in this investigation to develop a repair technique for high strength aluminium alloy components. High strength aluminium alloys are used in a variety of situations due to their good combination of high strength and low density. Repair of such components has the potential for cost savings for both the defence and aerospace sectors. Aluminium alloy 7075 powder was laser clad onto a substrate of 7075 and the character of the microstructure in both the clad layer and heat affected zone was evaluated. It was found that the fine precipitates that provide the strength in this class of alloy had grown and coalesced due to the heat supplied by the laser and weakened the heat affected zone from a structural point of view. A solution heat treatment and T6 aging procedure was applied to restore the strength in this region. After the heat treatment, hardness traverse profiles revealed that the hardness in the clad layer was lower than that of the substrate. This was attributed to the evaporation of magnesium and zinc during cladding and the higher concentration of iron in the powder forming an insoluble phase with zinc and magnesium in the clad layer. Both of these factors ultimately reduce the volume of the strengthening phases.

1. INTRODUCTION

Laser cladding is a maturing technology, where a traversing high power laser is used to melt a small area of the substrate, which acts to trap and melt incoming powder particles. This process results in the formation of a new layer. Rastering the beam with a predetermined inter-track spacing allows an area of built up material to be formed. The primary use of laser cladding has been the application of wear and corrosion resistant coatings [1, 2]. Recently there has been interest in using laser cladding as a repair technology for components suffering from foreign object damage, corrosion and wear. To meet the specification of the original components the damaged component is laser clad with the same material. For example the repair of titanium based turbine blades has been achieved by the cladding of Ti6242 on the Ti6242 blade [3]. The repair of single crystal superalloy turbine blades has been theoretically determined for cladding the same material [4].

The laser cladding of aluminium alloys has received attention and for all cases has involved the cladding of an aluminium silicon alloy on AA7075 substrate. It was found that increasing the silicon content of the alloy suppressed the formation of cracks during cladding [5]. It was also found in this study that porosity is a problem, which is consistent with the aluminium laser welding literature [6, 7]

and is due to hydrogen pick up from oxides in the substrate and condensation on the powder. It has also been shown that reducing the level of dilution through cooling of the substrate helped to reduce cracking and porosity [8]. A parametric study of the laser traversing speed and power showed that a combination of a high laser power and a high laser traversing speed increased the quality of the clad layer [9]. It was also mentioned in this work that aluminium has some physical properties that make it challenging to process with a laser. These include, a high reflectivity of visible and infrared light making coupling of the laser low, and a high thermal diffusivity which makes controlling the dilution and the size of the heat affected zone (HAZ) difficult.

This study evaluates the laser cladding of AA7075 powder on an AA7075 T6 substrate with and without a post heat treatment, with the aim of producing a clad and heat affected zone that is of the strength of the original component.

2. EXPERIMENTAL PROCEDURES

Laser cladding was conducted with 2.5kW Rofin-Sinar Nd:YAG laser, where the powder was supplied by a side injecting nozzle. The laser was delivered with a 0.6 mm diameter step-index optical glass fibre terminated with collimating and focussing lenses of 200 mm focal length positioned to produce a Gaussian laser spot size of 3 mm.

An aluminium 7075-T6 plate, 300 mm by 300 mm by 6.25 mm thick was used as the substrate. The surface was grit blasted just prior to cladding to remove surface oxides and other forms of contamination. Several combinations of laser power and traversing speed were trialled. A laser power of 2378 W (full power) at a laser traversing speed of 1900 mm/min, was used to produce the samples for subsequent metallurgical evaluation. The clad layer was formed by a raster of 10 mm with a 0.3 mm inter-track spacing. The raster was completed after 200 mm length of clad layer had been formed. The cladding was performed on a water cooled aluminium plate to control dilution and suppress thermal cracking. The side injecting nozzle was positioned at 30 deg from normal and in line with the scanning direction. The powder was an AA7075 composition powder (Table 1) supplied by Valimet and had a particle size range between 50-100 μm .

From the length of clad track, samples were cut parallel to the individual track direction for heat treatment. The heat treatment conducted was a solution heat treatment for 1.5 hours at 490 °C, quenched in water and then aged at 121 °C for 24 hours. Grinding and polishing down to colloidal silica polishing liquid was performed on both the as clad and heat treated samples for SEM and optical microscopy. SEM was conducted on a field emission Zeiss 40VP supra microscope to qualitatively evaluate the precipitate size of pre and post heat treatment. These samples were then etched using Keller's reagent and viewed under an optical microscope. Microhardness traverses were also conducted on a Buehler microhardness tester with a load of 300 g. The composition of the powder, substrate and clad was measured using ICP-AES (Inductive Coupled Plasma – Atomic Emission Spectrometry).

3. RESULTLS AND DISCUSSION

3.1 As Clad and Heat Treated Optical Macro and Microstructures

The macrostructure of the clad layer shows that the melt pool has penetrated deeply into the substrate, relative to the clad height. The high thermal diffusivity of aluminium and its alloys results in large amounts of power being required to melt the material. Once the power level is achieved for melting, small variations in the power level will result in significant changes in the melt pool depth.

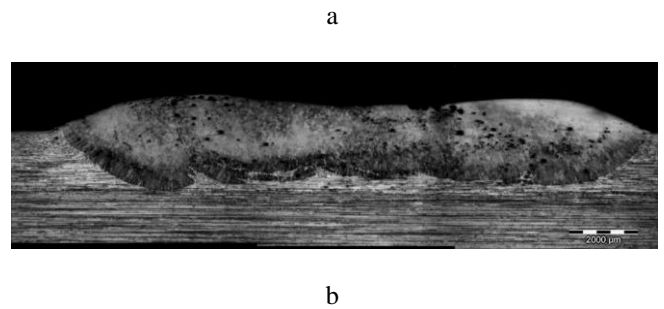
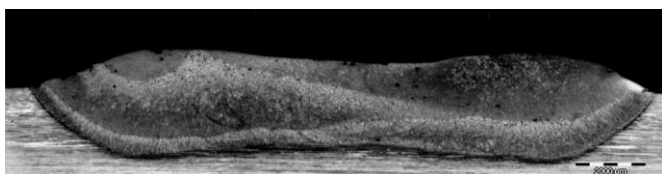


Fig. 1 – Optical micrograph of section of clad produced by 7075 powder clad onto 7075 substrate with a cladding speed of 1900 mm/min and a power of 2378 W, with a Gaussian spot size of 3 mm, taken parallel to the individual track directions; a –as clad; b – heat treated

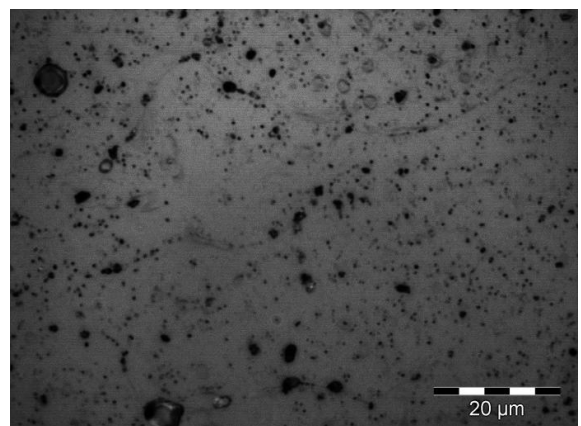
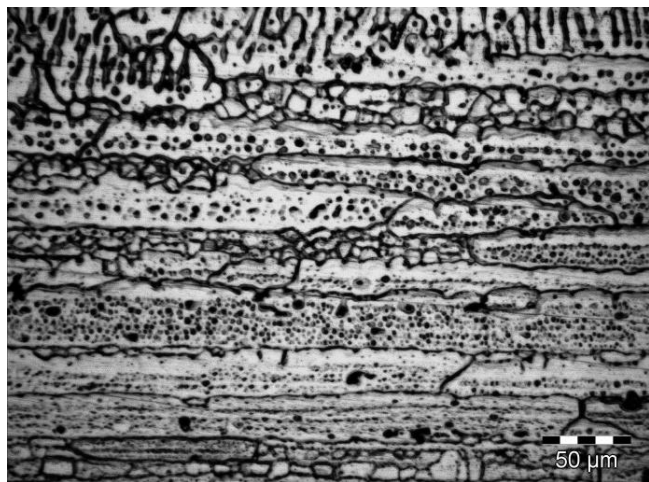


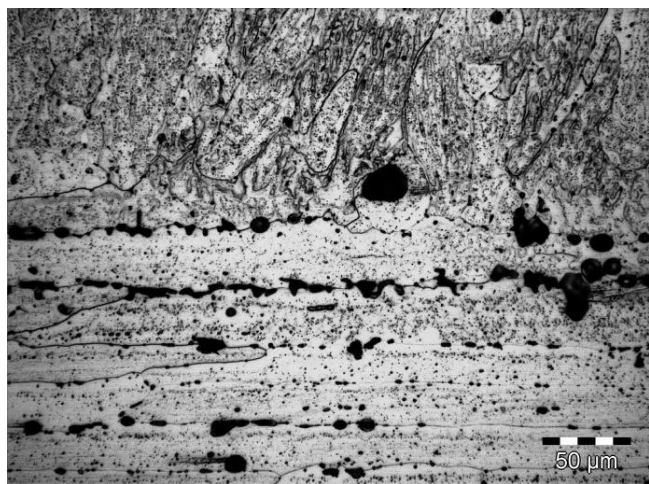
Fig. 2 – Optical micrograph of the clad produced by 7075 powder clad onto 7075 substrate with a cladding speed of 1900 mm/min and a power of 2378 W, with a Gaussian spot size of 3 mm, region; a – as clad; b – heat treated

The microstructures in the clad region before and after heat treatment both show the presence of second phase particles. The size of these second phase particles has been reduced

due to the heat treatment. It is apparent that the grains structure observed in the clad layer is equiaxed.



a

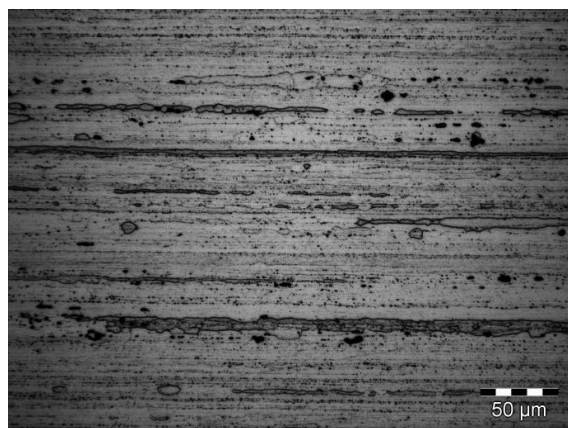


b

Fig. 3 – Optical micrograph of interface region of clad produced by 7075 powder clad onto 7075 substrate with a cladding speed of 1900 mm/min and a power of 2378 W, with a Gaussian spot size of 3 mm; a – as clad; b – heat treated



a



b

Fig. 4 – Optical micrograph of 7075 substrate; a – as clad; b – heat treated

The interface region, Figure 3, shows an abrupt transition from an equiaxed grain structure in the clad layer to an elongated grain structure in the substrate. The point of this transition indicates the level to which the melt pool reached into the substrate. The elongated grain structure of the substrate, Figure 4, is characteristic of the rolling process used to form the plate. The heat treatment carried out after cladding has not influenced the grain structure in the substrate.

3.2 Micro Hardness Traverses

Microhardness traverses of the clad layers before and after heat treatment are shown in Figure 5. The as clad sample shows a lower level of hardness and the clad region shows the lowest level of that traverse at around 100 HV. In the heat affected zone (HAZ) the hardness level increases slightly and then progressed the substrate where the hardness increases further. After heat treatment the hardness increases to 150 HV in the clad and 200 HV in the substrate.

Again the hardness in the clad region is not as high. These results are consistent with those when welding AA7075 with AA7075 filler rod [10]. To elucidate why the hardness increases after heat treatment and why the clad region has consistently lower hardness, SEM was employed.

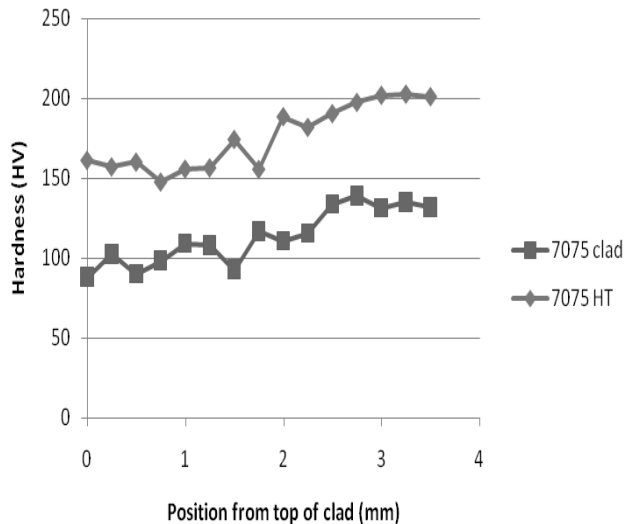


Fig. 5 – Microhardness traverses through the clad, heat affected zone and substrate for the as clad and heat treated specimens.

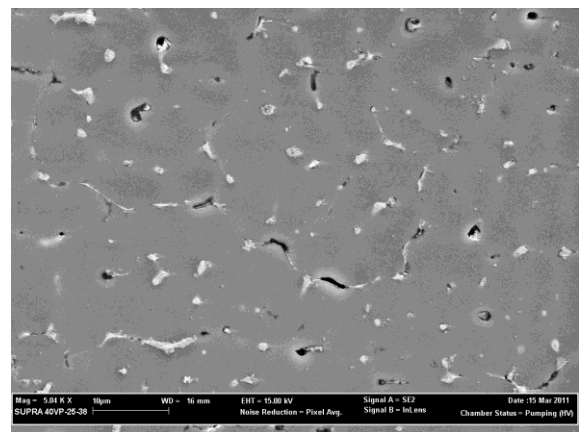
Table 1 shows that the magnesium and zinc are lower in the clad than in the substrate. This is not uncommon for zinc as it has a low vaporisation point and has vaporised during processing. Magnesium also has a relatively low vaporisation point but not as low as zinc and hence a small amount has been lost. There are two phases that provide the strengthening of the aluminium matrix. They are the η -Mg₂Zn phase and the S-Al₂CuMg phase[11]. Therefore the reduction of both the zinc and magnesium content in the clad layer would reduce the volume fraction of the two precipitate phases and hence the loss of strength in this region even after the heat treatment was obtained.

Table 1 - Composition of alloying elements for the three components of the clad in wt%

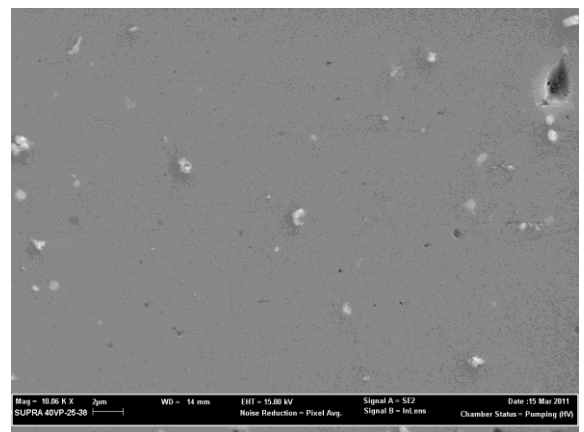
Sample	Al	Si	Cu	Fe	Mg	Zn	Cr
Substrate	Bal	0.06	1.41	0.19	2.43	5.52	0.24
Powder	Bal	0.16	1.55	0.27	2.56	5.49	0.21
Clad	Bal	0.1	1.44	0.24	2.15	4.53	0.24

3.3 SEM of Clad and Heat Affected Zones

The SEM images of the clad region of the as clad sample, Figure 6, show quite coarse second phase particles. EDS of the particles reveals that they are comprised of Zn, Cu and Al, and have the composition of S phase.

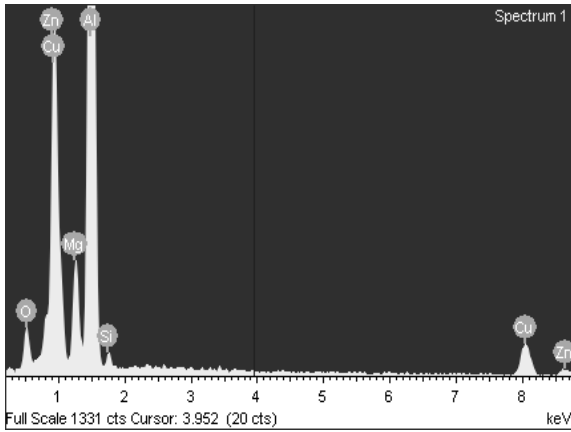


a

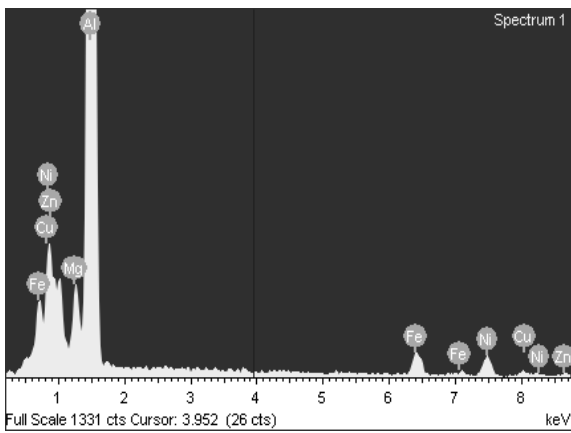


b

Fig. 6 – SEM of clad region produced by 7075 powder clad onto 7075 substrate with a cladding speed of 1900 mm/min and a power of 2378 W, with a Gaussian spot size of 3 mm, without heat treatment; a – secondary electron image; b – EDS X-ray spectrum



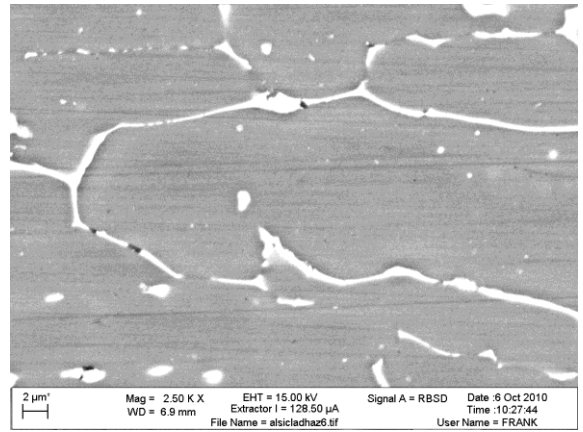
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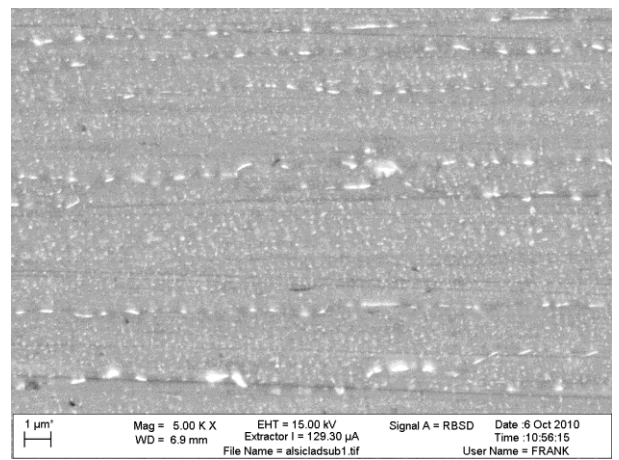
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Fig. 7 – SEM of clad region produced by 7075 powder clad onto 7075 substrate with a cladding speed of 1900 mm/min and a power of 2378 W, with a Gaussian spot size of 3 mm, after heat treatment; a – secondary electron image; b – EDS X-ray spectrum

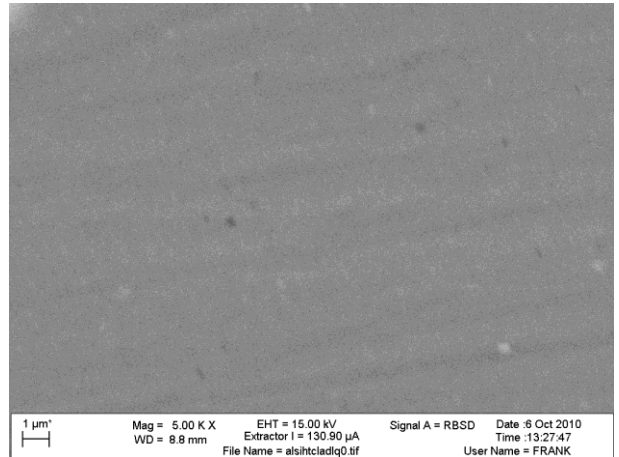
After heat treatment large particles remaining in the microstructure were still evident, Figure 7. EDS of these precipitates reveals Zn and Cu as well as significant traces of Fe. This is an insoluble phase and is the reason why it is still present after heat treatment [12]. Reference to Table 1 shows that the iron content of the powder is higher than that of the substrate and is the source of the iron for the precipitates formed. These precipitates effectively tie up Mg, which again reduces the volume of magnesium available to form η and S phase hence reducing the strength of the clad region.



a



b



c

Fig. 8 – SEM of heat affected zone; a – at interface; b – HAZ; c – after heat treatment

SEM image of the HAZ, Figure 8 shows the area adjacent to the interface. The particles appear to have segregated to the grain boundaries and deeper into the HAZ, indicating the strengthening phases have grown and coalesced, which is consistent with the welding of 7039 [13]. The increase in the size of the precipitates is responsible for the lower strength

of the as clad sample in Figure 5. After heat treatment the particles are so small that they cannot be detected by the FEG SEM and hence the strength in this region returns, Figure 5.

4. CONCLUSION

Laser cladding of AA 7075 alloy powder on AA 7075 T6 substrate free from cracking and porosity is presented. The precipitates in the HAZ grow and coalesce, which results in a reduction in strength of this region. The clad region shows low Mg and Zn contents which was attributed to evaporation during processing. This decreases the strength in the clad region for the as clad and heat treated conditions. Solution heat treatment and aging restores the strength in the HAZ and substrate. The hardness in the clad region increases, but not to the level of the substrate.

References

1. A. Frenk, M. Vandyoussefi, J.D. Wagniere, A. Zryd, W. Kurz: Metallurgical and Materials Transactions B, 1997, vol. 28, pp 501-508.
2. I. Hemmati, V. Ocelik, M.T.M. De Hosson: Journal of Materials Science, 2011, vol. 46, p p 3405-3414.
3. K.H.Richter, S. Orban, and S. Nowotny: Proceedings of the 23rd international congress on applications of lasers and electro-optics. 2004.
4. M. Gaumann, C. Bezencon, P. Canalis, W. Kurz, Acta Materialia, 2001, vol. 49, pp 1051-1062.
5. Q. Liu, P. K. Sharp, M. Brandt, Y. Durandet: Pacific international conference on application of lasers and optic. 2004, p p 28-32.
6. A. Haboudou, P. Peyre, A.B. Vannes, G. Peix: Materials Science and Engineering A, 2003, vol. 363,p p 40-52.
7. T. Luijendijk: Journal of Materials Processing Technology, 2000, vol 103, pp 29-35.
8. Y. Durandet, P. Kallage, M. Brandt: Pacific International Conference on Application of Lasers and Optics: 2004, p p 5-10.
9. Y. Durandet, M. Brandt, Q. Liu, Materials Forum, 2004, vol. 29, pp 136-142.
10. M. Temmar, M. Hadji, T. Sahraoui: Materials and Design, 2011, vol. 32, pp 3532-3536.
11. S.W. Kim, D.Y. Kim, W.G. Kim, K.D. Woo: Materials Science and Engineering A, 2001, vol. 304-306, pp 721-726.
12. *Aluminium and Aluminium Alloys*. ASM Specialty Handbook, ed. J.R. Davis. 1993, Ohio: ASM International.
13. I.B. Robinson, F.R. Baysinger, Welding Research Supplement, 1966, vol October, pp 433-444.