LASER CLADDING OF ALUMINIUM USING TiB_2

(Paper Number 1202)

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Abstract

Modification of Aluminium surface by injecting, dispersing and melting TiB_2 powder with the help of a laser beam promises to enhance tribological properties of Aluminium. The present work consists of making single lines and various overlapping lines of TiB_2 powder on an Aluminium substrate using Nd:YAG laser and analysing their microstructures and hardness. The role of various processing parameters such as laser power, scanning speed, laser beam diameter, percentage of overlap, powder flow rate on laser cladding has been described. It is possible to make a clad layer of uniform thickness of 0.55 mm having hardness of 100 HV.

Introduction

Laser surface treatment of light metals using laser cladding technique is one of the promising methods to improve surface mechanical properties of the metal. Aluminium is one of the light metals which is technically interesting because of its availability, cost and machinability but it lacks sufficient surface strength which hinders it to be used in many applications where tribological property is important.

Aluminium has been cladded with ceramics such as Si, SiC (1), TiC and various other metallic materials such as Ti, B, Ni (2) etc to enhance its surface properties. In case of modification using many ceramics, it has been found that they also chemically react with Al and form compounds which decrease the strength of Aluminium. Ni has also been widely used because it furnishes very high hardness and corrosion resistance but it also forms intermetallics with Al, which being brittle in nature decreases the high temperature properties of aluminium. In light of these occurrences, TiB_2 provides an ideal solution. TiB_2 is an extremely hard material, does not react with Al and provides high temperature stability. Though, aluminium matrix composite formed with TiB_2 does not give very high hardness, it promises to provide good wear resistance at room and high temperature.

Not much work has been done in

the application of TiB_2 for laser cladding of Al (3; 4) in comparison to that of steel (5) and Titanium (6; 7). Previous work consists of an effort to make deep laser injection of TiB_2 on Al or the creation of in-situ of TiB_2 using other reactant particles. In-situ creation of TiB_2 suffers from other side effects such as formation of other deleterious compounds in the matrix and lack of control of the process.

The present effort is concentrated on making a uniform clad layer of TiB_2 on an Aluminium substrate and studying the role of various factors on their formation.

Experimental

Machine and Materials

The experiment has been conducted with the help of a KUKA robot which is fitted with (1) a Rofin-Sinar Nd: YAG laser through optical fiber delivery system, (2) an off-axis nozzle of 2.5 mm diameter for powder delivery, the nozzle is fixed at a distance of 12 mm from the substrate, (3) an argon gas flow system around the laser beam. The various process parameters such as powder flow rate, laser power, scanning speed, percentage of overlap could be automatically controlled using the control panel of the robot. The schematic diagram of the process is shown in Figure 1.

The composition of the Al substrate (AA 1200) in wt % is given

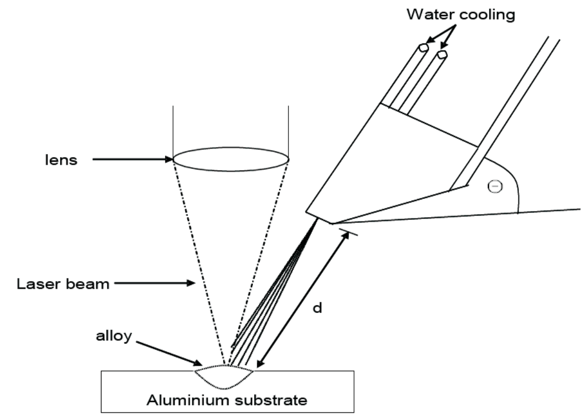

Fig. 1. Schematic diagram of laser cladding process using an off-axis nozzle

Si	Fe	Cu	Mn	Zn	Ti	Al
1.0	1.0	0.05	0.05	0.1	0.05	Bal.

Table 1
Composition of AA 1200 in wt.%

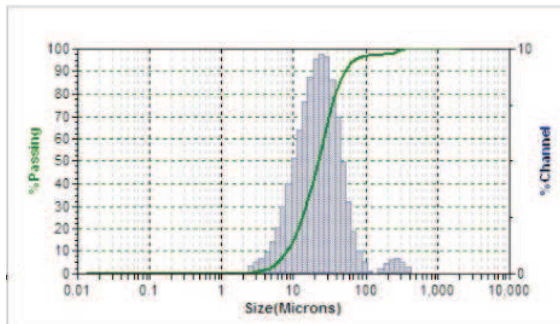

Fig. 2. Powder size distribution of TiB_2 showing the % passing against powder size

in Table 1. The powder size distribution of TiB_2 is given in Figure 2 which illustrates that the powder size varies from 8 to 70 μm. 60 % powder passes through a sieve of 26 μm size showing the mean size could be taken as 26 μm.

Experiments

Experiments were conducted in two steps. Firstly, single-lines experiments were made at a fixed beam diameter and varying the scan speed and laser power. These experiments were done to find the combinations of scan speed and laser power which can furnish higher hardness. Secondly, experiments were planned around these combinations of parameters besides varying the beam diameter, which were conducted for making various adjacent lines (multi-line experiments) at various percentages of overlap to determine the optimized laser cladding parameters. Both types of experiments are described below.

Single-line Experiments

Various lines of length 20 mm were made on the substrate (see Figure 3) using 2 rpm feed rate and 4 l/m carrier gas flow rate at scan speed varying from 0.005 to 0.04 m/s and laser power from 0.5 to 4 kW. The laser beam diameter was kept constant at 4 mm by maintaing a standoff distance of 240 mm from the lens to the substrate. In the 2nd step, some experiments have been done by changing feed rate and gas flow rate.

The powder flow rate (PFR) was determined by measuring the amount of powder collected in one minute at a given feed rate (FR) and carrier gas flow rate (GFR). FR is the rotation of wheel present in powder hopper used to feed powder to the pipe leading to the nozzle. GFR is the rate of carrier gas used to carry the powder from the hopper to the nozzle. PFR is the rate of powder accumulated on the substrate. Table 2 shows the PFR for TiB_2. The powder did not show the smooth flow because of the presence of smaller size powders.

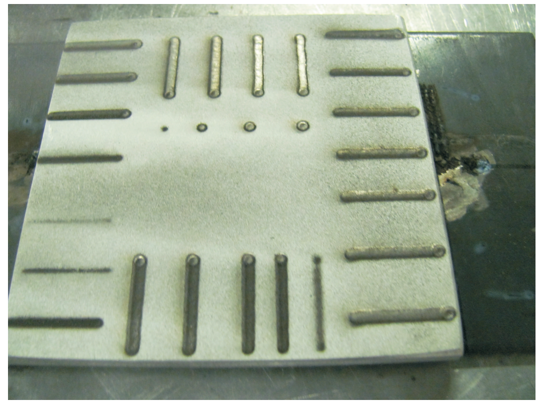

Fig. 3. Various laser clad lines made at various parameters at the substrate

It has been found that with an increase in FR, PFR increases while increase in GFR decreases the PFR because of increased deflection of powders from the substrate. This is evident from Sl. No. 2 and 3 (Table 2). In this case, an increase in GFR from 4 to 6 l/m has decreased the PFR from 1.30 to 0.85. Though, with an increase in GFR from 5 to 6 l/m, there is a slight increase in PFR, which could be attributed to the non-uniform flow of powder, which in turn does not give clad of uniform height.

Multiple-lines Experiments

These experiments were done at constant feed rate of 4 rpm and carrier gas flow rate of 6 l/m to make a clad area of a minimum of 2 cm x 2 cm. The laser power, scan

Sl. No.	FR (rpm)	GFR (l/m)	PFR (g/m)
1	2	4	0.46
2	4	4	1.30
3	4	6	0.85
4	2	5	0.45
5	2	6	0.48

Table 2
PFR of TiB_2

Sl. No.	P (kW)	v (m/s)	%	d (mm)
1	3	0.005	50	3
2	3	0.005	25	3
3	4	0.01	50	4
4	4	0.01	25	4
5	4	0.02	75	4
6	4	0.02	50	4
7	4	0.02	25	4
8	4	0.02	75	5
9	4	0.02	50	5
10	4	0.02	25	5
11	4	0.02	75	6
12	4	0.02	50	6
13	4	0.02	25	6

Table 3
Experimental parameters for multiple-line experiments at 0.85 g/min powder flow rate

speed, spot size (beam diameter), % overlap were varied from 3 to 4 kW, 0.005 to 0.02 m/s, 3 to 6 mm and 25 to 75 % respectively. The experimental parameters are given in (Table 3)

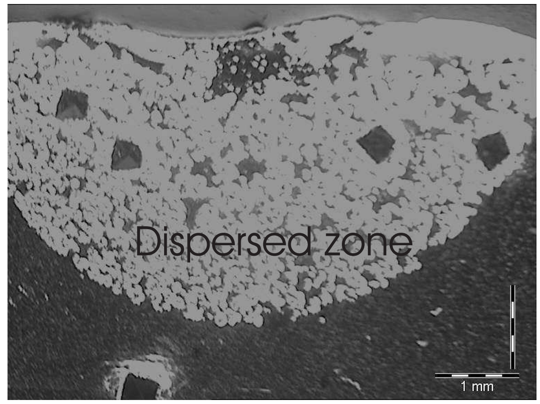

Fig. 4. An optical micrograph showing a semi-circle shape of dispersed zone

Results and Discussions

Cross-sections from samples obtained from both set of experiments were metallurgically prepared and etched using Keller's reagent. Vickers hardness was measured and the micrographs were observed/measured using optical and stereo microscope. Various results obtained for both set of experiments are described separately below.

From Single-line Experiments

Optical microscope (see Figure 4) was used to measure the dispersed zone (Z), i.e. the melted zone containing injected powders. Vickers hardness (HV) was measured using a load of 5 kg, time 10 sec. It was observed that particles were not injected dense enough and measuring the microhardness using smaller loads would not furnish a representative hardness of the dispersed zone. A higher load of 5 kg gave an indentation of about 500 μm covering sufficient number of particles, giving the hardness

P (kW)	v (m/s)	E (MJ/m^2)	Z (mm)	HV
4	0.01	100	1.23	33
3	0.01	75	1.12	30
3.5	0.04	22	0.98	31
4	0.04	25	1.00	33
4	0.03	33	1.00	35
4	0.02	50	1.05	39
4	0.05	20	1.00	31
4	0.05	18	0.95	30

Table 4
Dispersed zone depth, hardness and energy density for single-line experiments at constant 0.46 g/min PFR

PFR g/min	P (kW)	v (m/s)	E (MJ/m^2)	Z (mm)	HV
1.30	4	0.01	100	1.11	33
0.85	4	0.005	200	1.55	43
0.48	3	0.005	150	1.13	46
				1(clad)	102
0.45	4	0.0025	400	3.53	41

Table 5
Dispersed zone depth, hardness and energy density for single-line experiments at various PFR

of the zone. The hardness values measured for selected samples, depth of dispersed zone (Z) and energy density (E) are shown in Table 4. Energy density (E) is defined by laser power (P) devided by beam diameter (d) and scan speed (v). E= P/d.v. The experiments and results at various PFR are given in Table 5.

Table 4 does not show many combinations of parameters which failed to give any substantial hardness. Such parameters are all laser power less than 2.5 kW. Combinations such as laser power 3 kW at speeds 0.02, 0.03, 0.04 m/s or 3.5 kW and 0.03 m/s also did not give good result. Though, energy density for them are more than those obtained at higher laser power and higher scan speed showing that the laser power is the dominant factor and energy density is not the right parameter to compare between two combinations having different laser power. But, for a given combination, energy density showed a trend, i.e. with an increase in E, there is an increase in hardness and dispersion zone. Increase in laser power has increased the dispersed zone depth. For a given laser power, with a decrease in scan speed has given rise to an increase in hardness, e.g. for 4 kW, with a decrease in scan speed from 0.05 to 0.02 m/s has increased the hardness from 33 to 39 HV. Though at 4 kW, 0.01 m/s, the hardness is 33 HV, this anomaly could be attributed to the non-smooth flow of TiB_2 at the onset of the experiment. The trend has also been confirmed from the results obtained from the tests as shown in Table 5. It clearly shows that with a decrease in scan speed from 0.005 to 0.01 m/s at 4 kW, the hardness has increased from 32.5 to 43 HV.

From Table 5, comparison shows that with a decrease in power from 4 to 3 kW, dispersed zone depth decreases from 1.55 to 1.13 mm,

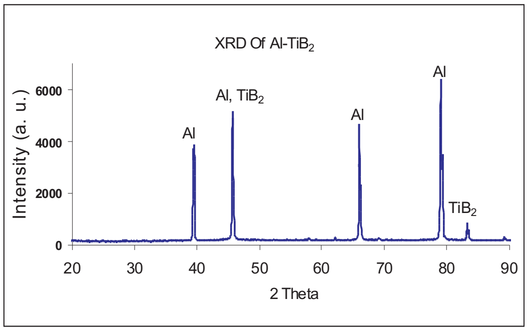

Fig. 5. XRD of laser cladding Al-TiB_2

the hardness increases from 43 to 46 HV. This could be attributed to the fact that with almost the same powder flow rate , more injecting particles need to be accommodated in the smaller dispersed zone giving rise to an increase in the density of particles resulting in an increase in the hardness. Hardness was also measured on the clad zone which had a height of 1 mm, it gives a very high hardness of 102 HV. This high hardness is due to the fact that clad zone has a high density of TiB_2 particles. XRD of some samples have been taken using radiation from Cu source and it is found that no phases other than Al and TiB_2 has been formed (see Figure 5). The single-line experiments have given simple inference that high hardness could be obtained by increasing the density of TiB_2 particles in the melted zone.

From Multiple-lines Experiments

These experiments were done for some parameters suggested by previous single-line experiments. Therefore, it was expected that better results would be obtained. The injected particles were so dense that Vickers hardness measurement gave acceptable results at 1 kg. Stereo microscope besides optical microscope was used to study various zones such as melting zone, dispersed zone and clad zone. The experimental parameters and the results are given in Table 6.

Sl. No.	E (MJ/m^2)	Z (mm)	%
1	200	1.2	50
2	200	1.30 (b),0.48 (s)	25
3	100	0.96 (b), 0.65 (s)	50
4	100	0.77 (b), 0.23 (s)	25
5	50	0.55	75
6	50	1.49	50
7	50	1.70 (b), 1.25 (s)	25
8	40	0.73 (b), 0.40 (s)	75
9	40	0.50 (b), 0.16 (s)	50
10	40	0.60(b), 0.04 (s)	25
11	33	0.55	75
12	33	0.41 (b), 0.10 (s)	50
13	33	0.36(b), 0.04 (s)	25

Table 6
Dispersed zone depth and energy density for multiple-line experiments at 0.85 g/min PFR

An optical micrograph has been taken at one of the clad zone, it shows the various original particles (grey areas) surrounded by melted zone (grey and white areas). Grey areas are TiB_2 particles either in original form or melted form and white areas ar Al. The resulting clad zone is an aluminium matrix composite reinforced with TiB_2

particles. Image analysis has revealed that about 15% areas are made of TiB_2 (see Figure 6).

Stereomicroscope was used to take the various micrographs which show that all dispersed zones were surrounded by melted zone of base material which is almost three times bigger than dispersed zone. Besides, the melted zone becomes wider as one goes from first scan to last scan. It depicts that with successive scan, heat from laser gets accumulated which caused a tapering in the size of clad zone (see Figures 7, 8)

Hardness has not been noted in Table 6 because hardness of melted zone of all experiments have been found to be 100 HV. In two cases: No. 6 and 7, hardness was lower about 45 HV, it is because particles get dispersed wider and resulting in lower density/hardness. It could be attributed to the non-uniform flow of powder. In the table the letter 'b' and 's' stands for big and small respectively (see Figure 9 for clarification). It is respectively showing the biggest height of the cladding zone at the peak and the smallest height at the overlap area. It has been found that at 75 % overlap, uniform cladding zone has been obtained, e.g. No. 5 and 11. As the % overlap is decreased, the difference between 'b' and 's' has increased. It shows that for getting a uniform zone sufficient overlap between two successive scans is necessary.

The uniform clad has also been of

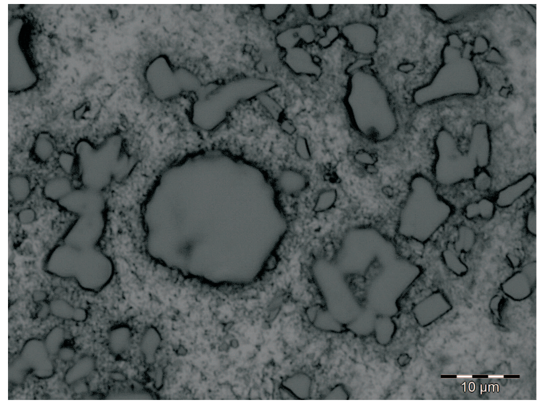

Fig. 6. Optical micrograph at 1000 magnificationn of uniform clad zone

smaller thickness than that made at lower overlap corresponding to the same process parameters, it shows that successive laser pass has remelted the peak and leveled it to a lower height. It could be clear by comparing Nos. 1 and 2 which shows that total clad thickness decreases from 1.30 to 1.2 mm with an increase in overlap from 25 to 50 %. The same can also be observed from other cases such as 5 and 7, 11 and 12 etc (see Table 6).

SL No. 5 and/or 11 (see Table 3) has given a uniform clad zone of 0.55 mm (see Table 6) making the experimental parameters corresponding to these experiments as optimized parameters. The optimized parameters could be 4 kW power, 0.02 m/s scan speed, 75% scan spacing overlap and 4 or 6 mm spot diameter.

Conclusion

It is possible to laser clad a thickness of about 0.50 mm uniformly on Al sufficient for many wear and corrosion applications. Hardness of the clad or dispersed zone de-

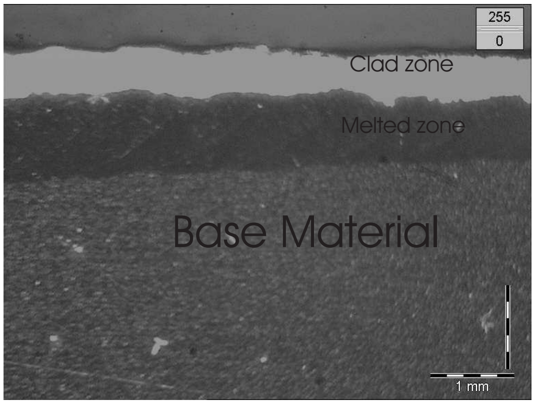

Fig. 7. stereomicrograph of No. 5 showing clad zone and melted zone which gets tapered shown at the left side

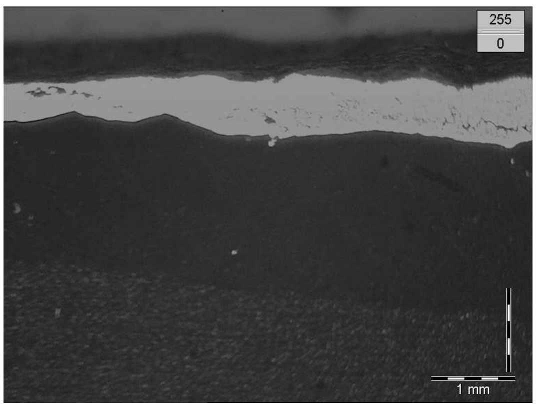

Fig. 8. stereomicrograph of No. 8 showing clad zone and melted zone which gets tapered shown at the right side

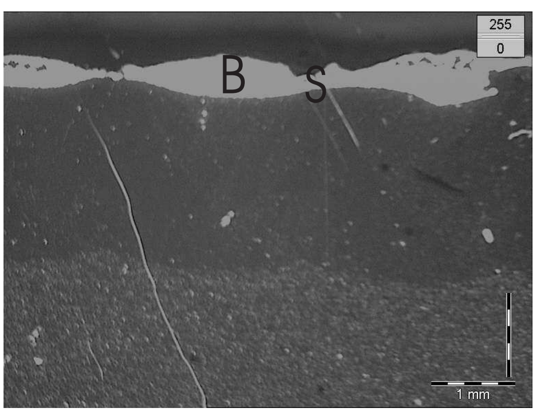

Fig. 9. stereomicrograph of No. 9 showing the wavy nature of clad for clarifying the meaning of 'b' and 's'

pends on the number of TiB_2 in the base material. With an increase in a density of injected particles, the hardness increases and reaches to a maximum of 100 HV.

The obtained results show that the treated substrate shows the highest hardness possible with the experimented ceramics. Though, for industrial application, some problem of heat accumulation need to be solved which will not be as severe as in our case because in larger application, scanning length would be higher and the substrate will get enough time to cool resulting in formation of uniform property zone.

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