Development of Metal Matrix Composite by Laser Surface Alloying

Jyotsna Dutta Majumdar
Dept. of Metall. & Maters. Engg., Indian Institute of Technology Kharagpur, W. B. -721302, India
jyotsna@metal.iitkgp.ernet.in

Abstract— Laser as a source of focused energy may be applied for the modification of microstructure and/or composition of the near surface region. The technique may be applied for the development of a ceramic/intermetallics/ interstitial compound dispersed metal matrix composite layer on the surface of metallic substrate by melting the substrate with a high power laser and simultaneous addition of alloy powders for the development of metal matrix composite layer by in-situ reactions. In the present contribution, development of metal-dispersed and intermetallic-dispersed matrix composite layer on the surface of metallic matrix has been discussed with a suitable example of its application.

Keywords—Laser, composite, steel, titanium, magnesium.

I. INTRODUCTION
Laser as a source of monochromatic and coherent radiation may be applied for the modification of microstructure and/or composition of the near surface region of the component and is commonly termed as laser surface alloying [1]. The choice of alloying elements plays a crucial role in determining the microstructures and the properties of the tailored surface. Metal matrix composites are new class of materials that exhibit good wear resistance property [2]. Laser melting of substrate and subsequent feeding of ceramic particles into the molten matrix is an effective means of development of composite layer on the surface may be termed as [2]. Several attempts have been made to develop a composite layer on mild steel, aluminium and magnesium substrates [3]. However, a precise control of the distribution of particles, dissociation of particles during laser processing and difficulties in dispersing particles with fine particle size are the problems associated with the development of ceramic dispersed metal matrix composite by external addition of powders. The above mentioned problems may be circumvented if the dispersoids are developed by in-situ reaction during laser surface alloying by addition of suitable reactants as precursor. In the present contribution, the strategies of the development of metal matrix composite on metallic substrates have been discussed.

II. Cr DISPERSED Cu MATRIX COMPOSITE SURFACE ON Cu
In the present investigation, dispersion of fine chromium on copper surface was attempted by laser surface melting of pre-deposited chromium (deposited by electro-deposition to a thickness of 10 µm and 20 µm) with a 2 kW continuous wave (CW) CO_{2} laser with a beam diameter \(d\) of 1 mm at focus and protective argon shroud (to avoid oxidation during lasing). The microstructure and composition of the alloyed zone have been studied by optical (OM) and scanning electron microscopy (SEM), X-ray diffractometry (XRD), energy dispersive spectroscopy (EDS), etc. The degree of superficial hardening was estimated through microhardness \(H_{v}\) measurements using Vickers microhardness tester both on the top (or lased) surface and cross sectional plane. Erosive wear was studied by fixing the specimens on to a vertical stirrer rod at an inclination of 30° (between the specimen and fluid surface) and rotated at 750 rpm in a slurry bath containing 20% sand dispersed in a viscous oil (specific gravity of 0.8) to carry out an accelerated erosion test running for a period up to 30 h. The bath was agitated for 50 min prior to each erosion test to ensure a uniform dispersion of sand particles in oil. Similar tests were also conducted in an identical medium isothermally heated between 300 and 450 K for time up to 30 hrs. Subsequently, the specimens were weighed at a pre-determined interval to monitor the change in weight per unit area \((-m)\) as a function of time \((t)\).

Fig. 1 shows the scanning electron micrograph of the top surface of laser surface alloyed copper with chromium using a continuous wave CO_{2} laser with a power of 2 kW, beam diameter of 1 mm and protective argon shroud. Fig. 1 evidences that the AZ indeed contains a uniform distribution of spherical Cr-rich precipitates in the Cu matrix. The density of such precipitates is more for a pre-deposit thickness of 10 µm as compared to that of 20 µm under comparable conditions. However, the particle size and morphology remain identical in either case. More importantly, the precipitate distribution does not significantly vary with the depth. Total Cr content, Cr in the form of precipitates and Cr in solid solution with Cu in the alloyed zone were determined by energy dispersive spectrometry, optical microscope and X-ray diffraction technique, respectively. Laser surface alloying extended the solid solubility of Cr in Cu as high as 4.5 at. % compared to less than 1 at. % under equilibrium condition. The microhardness of the alloyed zone was found to improve significantly (as high as 225 VHN) following laser surface alloying as compared to 85 VHN of the base metal. Since hardness is related to Cr present in solid solution and dispersed as precipitates in the matrix, the variation of average microhardness of the alloyed zone as a function of the total Cr-content, Cr dissolved in solid solution or volume fraction of Cr precipitated shows that hardness increases with all these microstructural factors, especially with the degree of solid solubility extension of Cr in Cu [4]. The microhardness of the
alloyed zone decreased with increase in energy density at a given pre-deposit thickness (t_z) which is attributed to a lower value of chromium in solid solution and dispersed form at a higher energy density due to an increased dilution [4]. Fig. 2 compares the material loss (Δm) of Cr dispersed Cu with that of Cu as a function of temperature for 24 hrs of immersion test in a slurry bath containing 20 wt. % sand dispersed in oil. In addition to reducing the magnitude of erosion loss (Δm) by over an order of magnitude, laser composite surfacing has significantly decreased the kinetics of erosion loss as compared to pure Cu under comparable conditions. Though the extent of material loss increases with an increase in temperature for both pure Cu and Cr dispersed Cu, the rate of erosion loss in Cr dispersed Cu is negligible as compared to the substantial change in erosion loss with temperature change for pure Cu, especially beyond 370 K.

![Image of scanning electron micrograph of the Cr dispersed Cu surface](image1)

**Figure 1:** Scanning electron micrograph of the Cr dispersed Cu surface (power density: 1590 MW/cm², interaction time: 0.08 s).

![Graph showing variation of erosion loss as a function of temperature](image2)

**Figure 2:** Variation of erosion loss (Δm) as a function of temperature (T) for 24 hrs of erosion.

III. Ti₅Si₃ DISPERSED α-Ti MATRIX COMPOSITE SURFACE ON Ti[6,7]

In this study a Ti₅Si₃ dispersed α-Ti matrix surface was developed on α-Ti matrix by laser surface melting of titanium using a 6 kW continuous wave CO₂ laser with a rectangular beam of 3.45 mm x 2.4 mm beam area and simultaneous addition of Si powder (particle size 22-45 μm) through an Ar gas driven (at a flow rate of 6 l/min). Fig. 3 shows the scanning electron micrograph of the top surface of laser surface alloyed Ti with Si lased with a power of 4 kW, scan speed of 300 mm/min and powder feed rate of 17 mg/s. The microstructure consists of uniformly distributed faceted Ti₅Si₃ phase in a two-phase eutectic aggregate of α-Ti and Ti₅Si₃. The Si content in the alloyed zone varied from 12-14 wt. %. The degree of fineness of the eutectic products signifies a complete dissolution and uniform intermixing of Si in the alloyed zone during melting, and a rapid quenching experienced by the latter, respectively. Fig. 4 shows the variation of depth of scratching with load due to scratching of pure Ti and laser surface alloyed Ti with Si with a hardened steel ball. It may be noted that scratch depth varies linearly with load for all the cases. The effect of load on scratch depth is more prominent at higher number of scratching (≥ 1000) than that at a lower value of the same (≤ 25). Under comparable conditions of scratching, Ti undergoes the most rapid wear loss followed by that in laser surface alloyed specimens. The laser alloyed sample with Si undergoes the minimum wear loss. The improved wear resistance of laser surface alloyed Ti with Si was attributed to the formation of a hard Ti₅Si₃ precipitates in the alloyed zone. Similar attempts were extended for the development of Mg₁₇Al₁₂ dispersed intermetallic in α-Mg matrix, Mg₂Ni dispersed intermetallics in α-Mg matrix, TiB dispersed intermetallics in α-Ti matrix, iron silicide and iron nitride dispersed surface on mild steel and titanium dispersed surface on α-Ti [8-10]. However, the alloying element and process parameters should be carefully chosen so that it’s miscible in the liquid state and forms intermetallics while solidification.

![Image of scanning electron micrograph (SEM) of the top or laser alloyed surface of Ti with Si](image3)

**Figure 3:** Scanning electron micrograph (SEM) of the top or laser alloyed surface of Ti with Si.

![Graph showing comparison of wear of as-received vis-à-vis laser surface alloyed Ti as a function of no. of cycles](image4)

**Figure 4:** Comparison of wear of as-received vis-à-vis laser surface alloyed Ti as a function of no. of cycles (n_w) / time of wear (t_w)
IV. TIB₂ DISPERSED AISI 304 STAINLESS STEEL MATRIX COMPOSITE SURFACE ON AISI 304 STAINLESS STEEL

In-situ TiB₂ dispersed surface on AISI 304 stainless steel substrate was carried out by melting the AISI 304 stainless steel substrate using a continuous wave CO₂ laser and simultaneous deposition of a mixture of K₂TiF₆ (potassium titanium hexafluoride) and KBF₅ (potassium hexafluoroborate) (in the weight ratio of 2:1) using Ar as shrouding environment at a powder feed rate of 4 g/min [11]. The microstructure of composite layer consisted of dispersion of titanium boride particles in AISI 304 stainless steel matrix (Fig. 5). The microhardness of the surface was improved 250 to 350 VHN as compared to 220 VHN of the AISI 304 stainless steel substrate (Fig. 6). The mechanism of improvement in microhardness in the composite layer is due to both grain refinement and dispersion strengthening. It may be noted that both laser power and scan speed should be carefully chosen in order to achieve an improved microhardness of the composite layer. A detailed evaluation of wear behavior against hardened steel ball shows that the rate of wear is significantly reduced in laser composite surfaced AISI 304 stainless steel as compared to as received one. A significant improvement in wear resistance was also noticed against hardened steel ball.

Figure 5: Scanning electron micrograph of the top surface of laser composite surfaced AISI 304 SS with TiB₂.

Figure 6: Micro-hardness distribution with depth for laser composite surfaced AISI 304 SS with TiB₂ lased with (1) 1.5 kW, 500 mm/min, (2) 1.5 kW, 300 mm/min.

V. SUMMARY AND CONCLUSIONS

Laser surface alloying is an effective route in development of composite layer on metallic substrate by dispersion of fine metals or intermetallics. A few examples of application of the technique on copper, titanium and steel are presented. It was observed that fine chromium dispersion in copper matrix is feasible by laser surface alloying of copper with chromium by pre-deposition of chromium by electro-deposition and laser melting. Extension of solid solubility to a level of 4.5 at.% as compared to 1 at.% maximum solubility was achieved. Improvement on hardness is attributed to presence of chromium both in solid solution and dispersed form. Intermetallic dispersed metal matrix composite was reported to form on Ti (dispersion of Ti₅Si₃) and AISI 304 stainless steel (dispersion of TiB₂). In all the cases the interface was continuous and defect free. Furthermore, the precipitates were refined in nature. Dispersion of intermetallics improved the microhardness of the matrix with a significant improvement in wear resistance. However, optimization of laser parameters was essential to circumvent residual tensile stress on the surface and ensure a defect free composite layer.

ACKNOWLEDGEMENT

Technical discussions with Prof. I. Manna, Prof. A. K. Nath, Prof. Lin Li are gratefully acknowledged. Partial financial support from Department of Science and Technology (D. S. T.), N. Delhi, Council of Scientific and Industrial Research (C. S. I. R.), N. Delhi and Naval research Board (N. R. B.), N. Delhi is gratefully acknowledged.

REFERENCES