International Symposium of Research Students on Materials Science and Engineering
December 20-22, 2004, Chennai, India
Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras

LASER BORIDING OF AUSTENITIC TYPE 304L STAINLESS STEEL

J.P. Deebasree [1], R.Thirumurugesan[2], P.Shankar[2], R.V.Subba Rao[2], P.Gopalakrishnan[1] and M.Vijayalakshmi[2]
[1] *PSG College of Technology, Peelamedu, Coimbatore 641004*
[2] *Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, 603 102*

ABSTRACT

Although boriding is known to result in improved surface properties compared to carburising and nitriding, the sluggish diffusion kinetics and the resultant high susbtrate temperatures that are necessary, limits their wide-scale industrial application. To circumvent these problems, laser boriding of 304L stainless steel has been investigated in the present study. The maximum hardness obtained was about 1490VHN and 1900VHN on laser surface alloying with boron and B_4C powders respectively. XRD studies suggest the in-situ dissociation of B_4C on laser surface alloying, and subsequent formation of metallic boride phases. The effect of laser boriding on morphology and solute repartitioning effects is discussed.

1. INTRODUCTION

Boriding of steels has been reported to result in higher hardness, wear, oxidation and corrosion resistance, compared to other conventional thermo-chemical surface modification methods like carburizing and nitriding [1-2]. Borided surfaces can optimally develop hardness in the range of 1200 – 2000 VHN as compared to hardness in the range of 600 – 1000 VHN for carburising and 700 – 850 VHN for nitriding of plain carbon steels. Also, the high melting points of borides ranging from 2300 to 3300 K, the low volatility, low electrical resistivity, high hardness and high stability, render them of potential value in certain high temperature applications. The wear resistance of cold working tools is increased by 10 – 12 times and hot working tools and dies by 3-5 times as a result of boriding. Components that are case hardened by boriding are therefore excellent candidate materials for applications such as dies used for cold and hot deformation of metals, dies for casting of non-ferrous alloys, moulds for fire bricks, dies and tools used in ceramic industries and for powder compaction, screw conveyors, clutches, push cams, sand blasting equipment, mineral processing equipment, bushes for jigs and fixtures, automobile gears and so on.

Boriding of steels by a variety of techniques including, pack, molten salt electroless and electrolytic, have been well documented in the literature [3-4]. Boriding generally results in the formation of FeB and/or Fe_2B needle-like microstructure at the case. Such a microstructure results in the high brittleness of the boride layer. This does not permit the effective use of borided parts when subjected to impact and high local loads during operation. The breakdown of the needle structure at the surface towards achieving a globular microstructure, can substantially improve the surface toughness and ductility. Superplastic boronising has been suggested as an effective method to result in equiaxed boride grains with high toughness [5]. Laser surface modification of borided steels have also been shown to significantly improve the toughness of the case [6].

However, One of the main limitation of the boriding process is the sluggish kinetics limited by the solid state diffusion of boron through the borides. This necessitates the use of very high boriding temperatures, which could lead to significant distortion and deterioration of components and thereby limit the wide-scale industrial acceptance of this process. Also for applications requiring a modified case thickness in excess of about 100 μm, boriding by solid-state diffusion process would not be feasible for industrial application.

Boron alloying by surface melting methods offers an amicable solution to synthesize very thick and hard boride layers at the surface without deterioration of the bulk properties. Plasma Transfer Arc (PTA) process has been used to surface alloy tool steels with boron, resulting in a nearly 1.5 mm thick modified layer of about 1000 – 1300 VHN [7]. Laser boriding of steels has also been investigated starting with pastes of boron [8], CrB [9] and CrB_2 [10]. Laser boriding provides unique advantages for surface modification without microstructural deterioration or distortion of the bulk component and also provides opportunity for preferential localized modification of selected parts of the component depending on the application. I t is also a reasonably fast and reliable process for obtaining thick and hardened layers.

The objective of the present study is to investigate and compare the effect of laser boriding of 304L steels on the morphology and hardness, by using initial pastes of boron and boron carbide powders respectively.

2. EXPERIMENTAL PROCEDURE

The specimens to be surface modified were metallographically polished and ultrasonically cleaned. The pastes of boron and boron carbide powders were prepared using methanol and were applied on the surface of 304 L austenitic stainless steel for about 2mm thickness. The samples were then dried in an oven at a temperature of 120^0C. A CO_2 laser beam of 1.5 mm diameter with a power of 200KW was used for surface alloying the pre-deposited coating with the 304L surface. The laser beam was rastered over the surface at a speed of 240 mm min^{-1} and argon shielding was used to prevent oxidation. The microhardness profiles across the case were measured using a Leitz microhardness tester at a load of 50 g. The phase analyses were carried out using a Philips X-ray diffractometer, using Cu K_α radiation. The microstructures of the laser borided surface, as well as the cross-section of the specimens were investigated using a scanning electron microscope (Philips GX 30 ESEM). Compositional variations amongst the phases formed were analysed using a EDAX system attached to the SEM.

3. RESULTS AND DISCUSSIONS

3.1 Laser surface alloying with boron

Fig.1 shows the SEM micrographs of the specimens laser borided with a pre-deposited boron paste. The case thickness is found to be nearly 250 – 300 μm. Dendritic morphology of the borides on laser boriding is clearly evident from Fig.1a. The boride/matrix interface can be seen to be nearly planar and free of defects or voids.

Steel specimens borided by conventional process result in the formation of needle shaped borides. The presence of microcracks are also commonly observed within the hard case. In contrast, the absence of needle shaped borides in the surface modified layer, is expected to result in the enhanced case toughness on laser boriding. Also, no microcracks are observed in the laser borided case.

XRD investigations confirm the formation of Fe_2B, CrB_4, Cr_2B, and $Cr_{23}C_6$ phases on laser boriding. Gopalakrishnan et al [3] have shown the preferential segregation of selective elements like carbon, nickel and silicon away from boron rich precipitates on boriding. Similar effect of selective carbon segregation in between the boride phases may lead to the formation of chromium carbides although the carbon content of the 304L steel is only about 0.035 wt%.

Laser boriding results in a significant hardness of over 1490 VHN at the surface. A smooth gradient in hardness is observed as can be seen from Fig.2 .

3.2 Laser surface alloying with B_4C

XRD studies of the 304L stainless steel surfaces laser alloyed with boron carbide powders show the presence of FeB, Fe_2B, Cr_2B, $Cr_{23}C_6$, Fe_3C and B_4C phases. The B_4C, austenite and Fe_2B peaks are however of low intensity suggesting their low volume fraction. In addition to the phenomenon of preferential carbon enrichment in between the boride phases, the in-situ dissociation of B_4C can also provide as a source of carbon for the formation of significant fractions of chromium and iron carbides in the case. Similar observation on dissociation of CrB during laser boriding of steel has been reported by Glozman et al.[9].

Fig. 3(a,b) show the SEM micrographs of 304L stainless steel, laser surface alloyed with boron carbide powders. A case thickness of over 200 μm is obtained as is evident from Fig 3a. The coarse black precipitates seen in Fig.3a are the undissolved boron carbide particles. The boride/matrix interface can be seen to be nearly planar and free of defects. The presence of coarse and bulky precipitates in the laser melted zone can be seen in Fig.3 b. A transition zone close to the matrix interface consisting of fine eutectic boride structure of about 20-30 μm can also be seen from the figure. X-ray area mapping using EDAX, confirm the bulky precipitates to be rich in chromium, as can be seen from Fig.4. These could be carbides, borides or boro-carbides of chromium. It is also interesting to note that these precipitates are predominantly rich in chromium with small solubility of iron. However, there is a near total exclusion of nickel from such chromium enriched precipitates.

Fig. 5 show the microhardness profile across the cross-section of the surface, alloyed with a pre-deposited layer of boron carbide. The peak surface hardness achieved is about 1890 VHN. The higher hardness of these surfaces compared to those laser modified with a pure boron paste (Fig.2) could be possibly due to the presence of a small concentration of the hard undissolved boron carbide particles. Optimisation of the laser parameters to enhance the boron carbide fraction in the case to achieve higher hardness is in plan. The transition zone can be seen to have a hardness of about 800 VHN, matching with that expected from a eutectic microstructure of iron boride.

4. CONCLUSIONS

Laser boriding of 304L steel with a pre-deposited paste of boron and boron carbide has been found to result in a significantly thick surface modified layer with reasonably good microstructural integrity. No microcracks or voids are seen in the case and at the interface. Peak surface hardness of nearly 1490 and 1900 VHN have been achieved on surface alloying with powders of boron and B_4C respectively. Selective repartitioning of substitutional solutes resulting in a Ni depleted coarse chromium rich precipitates have been identified based on X-ray mapping studies using EDAX/SEM.

REFERENCES

1. T.S.Eyre, Wear, 34 (1975) 383.
2. D.N.Tsipas, Materials and Manufacturing Processes, 14 (5) (1999) 697.
3. "Interrupted Boriding Of Medium Carbon Steels", P.Gopalakrishnan, P.Shankar, M.Palaniappa and S.S.Ramakrishnan, Metallurgical & Materials Transactions A., 33A (2002) 1475.
4. P.Gopalakrishnan, Some refinements to boriding processes, Ph.D thesis, August, 1999, Bharathiar University, Coimbatore, India.
5. C.H.Xu, J.K.Xi and W.Gao, Scr. Mater., 34 (1996) 455.
6. P.Gopalakrishnan, P.Shankar, R.V.Subba Rao and S.S.Ramakrishnan, Scripta Materialia., 44 (2001) 707-712.
7. R.Iakovou, L.Bourithris and G.Papadimitriou, Wear 252 (2002) 1007
8. Tayal, M., Mukherjee, K., Journal of Materials Science 29 (1994) 5699.
9. Glozman, A.; Bamberger, M. , Metallurgical and Materials Transactions A: 28A (1997) 1699
10. G. Shafirstien and M. Bamberger M. Langohr and F. Maisenhalder Surface and Coatings Technology Volume 45, Issues 1-3 , 15 May 1991, Pages 417-423.

FIGURES

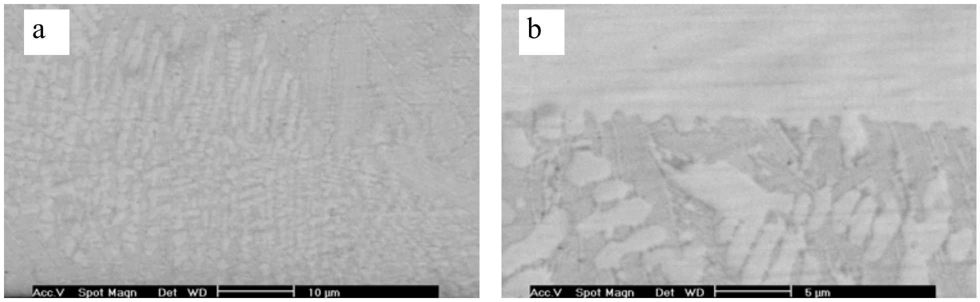

Fig. 1 : SEM micrographs of 304L stainless steel surface alloyed with a pre-deposited boron paste by laser treatment. (a) the typical dendritic morphology expected on laser boriding is evident (b) magnified image showing the nearly defect free interface.

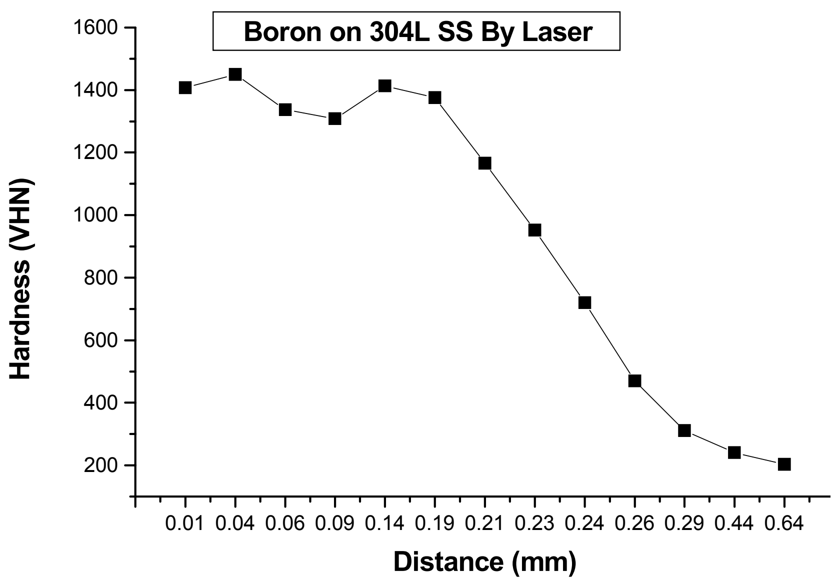

Fig.2 : Cross sectional microhardness profile across the 304L stainless steel specimen laser surface alloyed with boron.

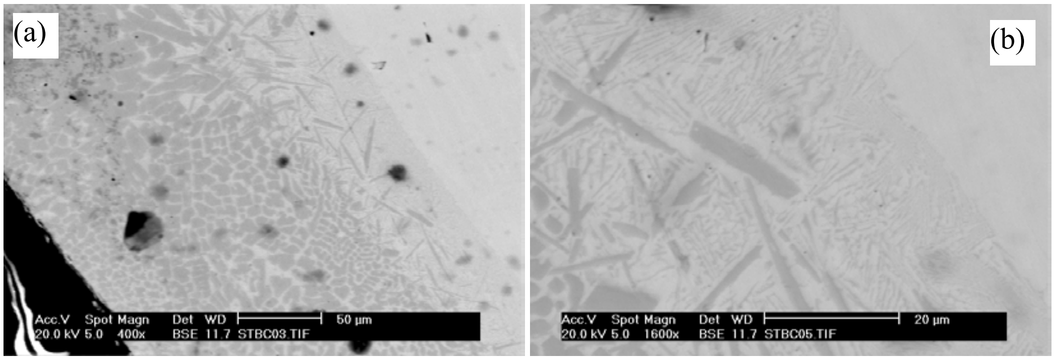

Fig 3 (a,b) : SEM micrographs of 304L specimens laser surface alloyed with B_4C powders

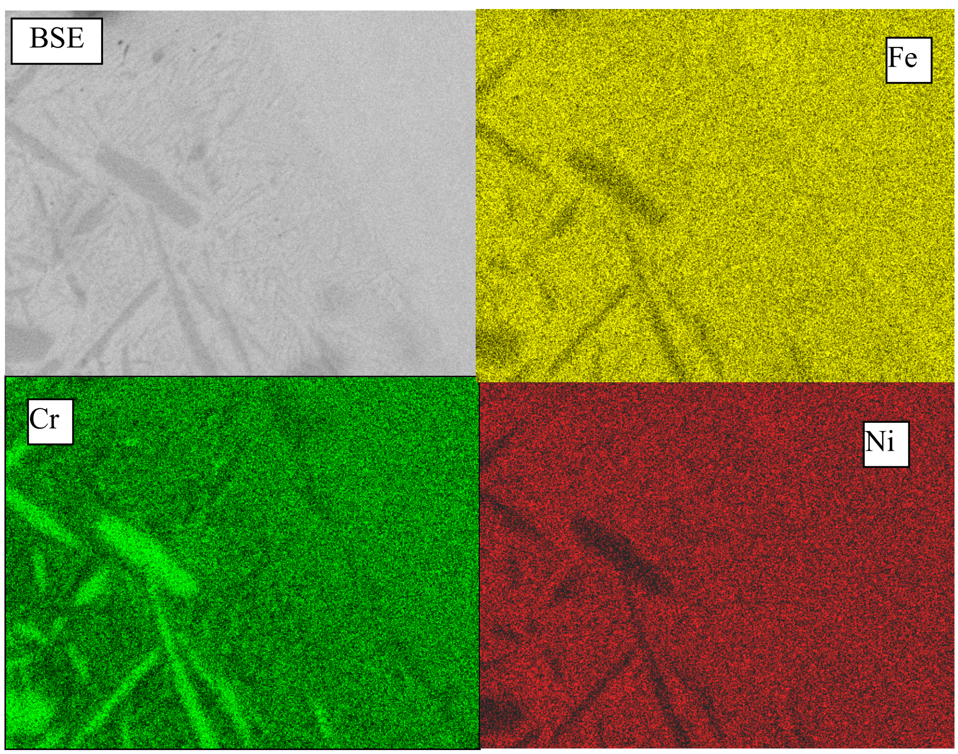

Fig. 4: SEM/EDAX X-ray mapping image showing preferential exclusion of Ni and Fe from the Cr rich precipitates in the laser modified zone.