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Improvement of Microstructure and Wear Resistance of X12 Tool Steel by Using Laser Surface Re-Melting Technique

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Abstract. Nd-YAG lasers have been successfully used in recent years as reliable heat source to surface modification of engineering materials such as laser surface re-melting. In the present study, X12 tool steel was surface modified by using pulse Nd-YAG laser technique. Laser parameters are selected of 12 J pulse energy, 15 Hz frequency, 20 mm defocus length, 6 ms pulse duration, and 5.6 mm /s mm scanning speed. These parameters were chosen after undertaking trials to give suitable parameters in this process. Optical microscopy and backscattered scanning electron microscopy (SEM) with EDS and X-ray diffraction techniques were used to analyse the microstructure changes of the surface of tool steel. Wear resistance test was achieved by using a pin on disk method. The reason for this work is to improve the wear resistance for surface layer of tool steel after changes the morphology of the structure by rapid solidification during laser re-melting. In general, the structure consists of the dendrite and cellular structures with δ ferrite formed under conditions of rapid solidification without the primary coarse carbides. After laser melting, the results of the structure at the surface layers show an increase in wear resistance.

Introduction

Tool steel considers one of the important materials in engineering applications. They are widely used for, dies, moulds, cutting tools, and other components making that are served under the high level of loads, to provide the required wear resistance [1].

Poor tribological and low wear resistance properties can shorten parts 'service life with intensive wear for manufacturing purposes. Accordingly, there is a growing interest in improving surface properties through different surface modification. The use of surface modification by laser to extend the service life of engineering components has been gaining rising acceptance in the last years [2, 3]. Laser surface engineering can be considered as a possible solution for modification of the surfaces of different solid materials [4, 21], since the ability of high-energy laser beams to produce rapid heating and cooling rates (10^3 – 10^6 °C/s) will result in changes in properties their surface. For example, grain refining, morphological change, compositional changes, and phase transformation through non-equilibrium cooling without alteration of the bulk properties [6, 7], and in many cases may be reached to amorphous structure [12,13, 14]. The initial structure of steel does not influence too much microstructure of the surface layers forming during its laser re-solidification. Only in the case of steels having very large carbide particles in the matrix un-dissolved carbides are still observed in the re-solidified layer [15, 16, 17, and 18] the thermos – physical properties of the used material, and laser traversing rate are directly affected by heating and cooling range [8]. The laser-heated area is very small. This tends to limit the warm damage in the laser surface re-melting of the workpiece [9]. The laser surface re-melting process tends to refine both solid solution (dendrite structure) and carbides [10]. The main aim of using laser surface melting (LSM) technique in surface processing is to enhance erosive, wear, and corrosive resistance because of the formation of the material surface layer's strong, homogenous and ultrafine structure without changing its chemical composition [5, 11]. Many different wear mechanisms, including abrasive wear, occur at the tool during machining. The presence of hard phases in the workpiece material, as well as hard particles removed from the tool, can generate abrasive wear on the tool surfaces [19, 20] This paper describes the experimental work on microstructural growth in surface modification of X12 tool steel by laser re-melting. Besides, the effect of laser re-melting wear behavior is investigated.

Experimental Work

Material

The used material in this study was the X12 tool steel, which has been supplied in an annealed condition. The chemical composition results by spectroscopy analysis technique of this type of steel are given in Table 1. The specimens were as disks with dimensions of (31*5) mm for diameter and thickness respectively.

Table 1: Chemical composition of X_{12} tool steel disc (wt. %)

Element	C	Mn	Si	Mo	Cr	S	P	Ni	Fe
Wt. %	2.0-2.3	0.27	0.40	0.24	14	0.040	0.024	0.25	84.5

At a magnetic grinding machine model UNI POL-820, the surface of the specimens was grinded with continuity cooling by water to high surface finishing. To avoid the microcracks, which can disqualify a sample for future testing, special care has been taken. On specimens which are so-prepared and fatless. Physical properties of the X12 tool steel are listed in Table 2 [23].

Table 2: Physical properties of X_{12} tool steel

Material	Melting point	Thermal expansion	Density	Modulus of elasticity	Poisson's ratio
X12 tool steel	1421[°C]	12 x 10^{-6} [m/ºC]	7.7 x 1000 [kg/m^3]	190-210 [GPa]	0.27-0.30

Laser Re-Melting Process

The specimens are cleaning with aceton to remove any contamination on surface before starting the laser work. For surface melting, a pulsed Nd:YAG laser (IQL-10) was used with the maximum average power of 400W was employed in the tests (see in Fig. 1). A pulsed Nd: YAG laser with a 12 J pulse energy, 15 Hz frequency, 20 mm defocus length, 6 ms pulse duration, and 5.6 mm /s laser scan speed parameters are used. Pure argon gas (99.99 percent) was coaxially blown with the laser beam onto the surfaces of the specimens at a flow rate of 10 L / min to protect the molten pool against oxidation, and other contaminations.

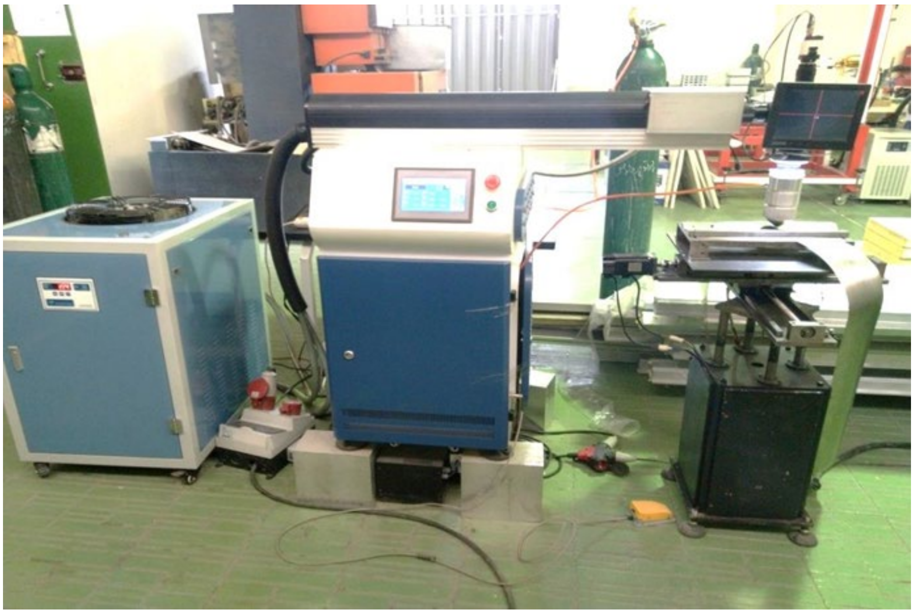

Fig. 1: Pulse Nd/YAG laser system used for re-melting of X12 tool steel specimens

Microstructural and Elemental Analysis

After laser modified process, the specimens were cross-sectioned by wire electric discharge machine (D-24647 Wasbek. Germany), and amounted with polyester as disk with dimensions of (30 X 5) mm for diameter, and thickness sequentially.

The standard metallographic method has been applied by grinding with SiC papers from 220, to 3000 sizes, 1 µm Al_2O_3 Paste polishing, and drying. Then, for each re-melted attempt, the samples were etched using 2 percent Nital at room temperature for the specific experimental time selected. The structural analysis was carried out using the Leica MEF4A light microscope. On each re-melted tray, the statement was prepared perpendicular to the sample cross-section. The metallographic analysis was also carried out using the electron microscope for the scanning to show the microstructural features of the melted laser region by Leo 440 Scanning Electron Microscope.

Additionally, energy-dispersive spectroscopy EDS (S50 FEI 2014) was used to elemental analysis of melted and heat-affected zones.

Wear Test

The wear testing was built up by using wear tester device type (MT-4003, version 10.0) (see in Fig. 2). A pin on disc method was used (the specimen as disk), and pin from alumina AL_2O_3. The hardness of alumina pin is 1500 HV, (6mm) diameter, and 0.02 µm surface roughness. The test was performed by applied (50) N utilizing loads, (400 rpm) rotational speed, overall sliding distance of 228 m and (30 min) sliding time (A reading is taken after every five minutes. The roughness was for specimens used were 0.2 µm.

Results and Discussion

XRD Phases Identification

Fig. 3 shows the patterns of x-ray diffraction of the major two phases that formed on the surface of too steel after laser re-melted. Iron and chromium carbides (Fe3C, Cr23C6) are identified by x-ray diffraction. These carbides formed after chemical reaction between the elements at high temperature. Carbides have high hardness to enhance the wear resistance of tool steel. Fig. 4 shows three regions including the laser melted zone 1, heat affected zone 2, and the base alloy 3 can be identified by the optical microscopic image.

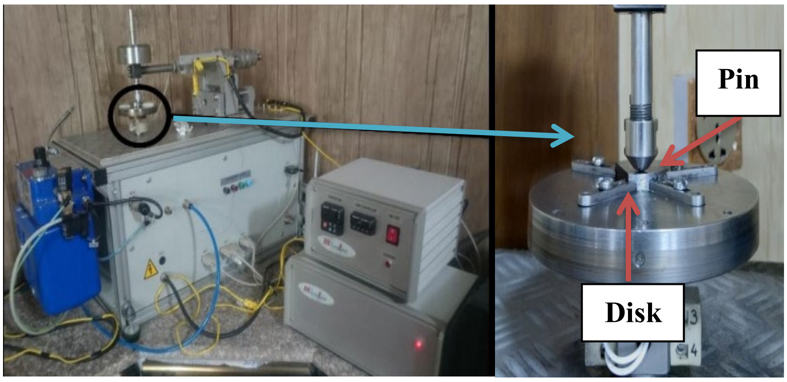

Fig. 2: Wear test device

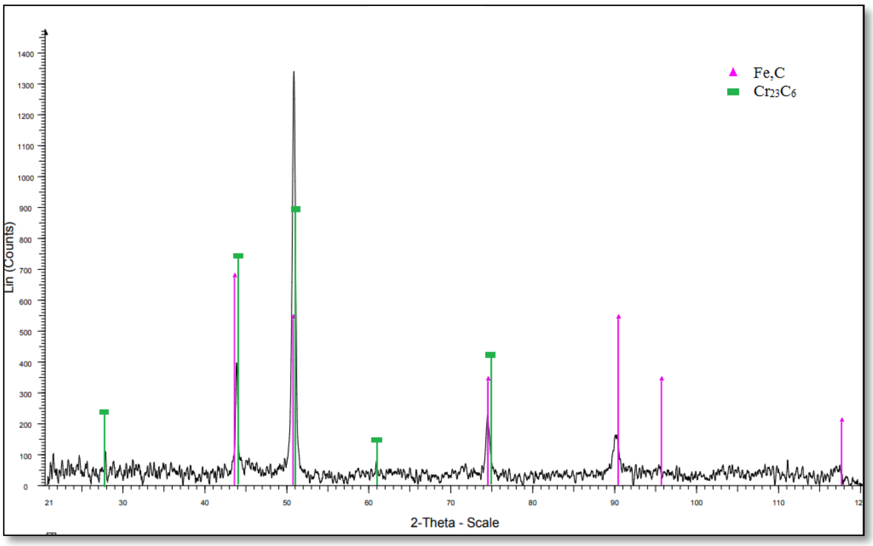

Fig. 3: XRD pattern of X12 tool steel after laser surface melting

Microstructural and Elemental

The width and average depth of the melted pool were around 1450 µm, and 200 µm respectively. The measurements of molten pools indicate that the laser surface melting was done in conductive mode.

The structure morphology of the melted zone is mainly depending on the temperature gradient solidification rate and cooling rate during laser process. The matrix of this structure is δ ferrite. The solidified zone seems the absence of carbide and all the carbide may be dissolved due to the high temperature of the laser process and with high heat intensity of the laser process. The role structure of the re-melted zone consists of cellular structure with δ ferrite, and a small percentage of dendrite see in Fig. 5. Cellular structure, formed due to high temperature gradient of laser process with rapid solidification. These results agree with Ref [19, 21, and 22].

Fig. 6 shows the microstructure at the interface between the melted zone and heat affected zone. The cellular structure started to change its morphology. It is observed a lamellar structure inside the grain as shown in Fig: 6-c and 6-d. Fig. 7, and Fig. 8 shows the distribution of carbides around the matrix of steel in heat affected zone, and not affected zone (base) respectively. Fines carbides are uniform distributed in the matrix and some of coarse or mass carbides are also observed. Iron and chromium carbides are identified by x-ray analysis. EDS is taken to elemental analysis of these carbides as seen in Fig. 9, and Table 3.

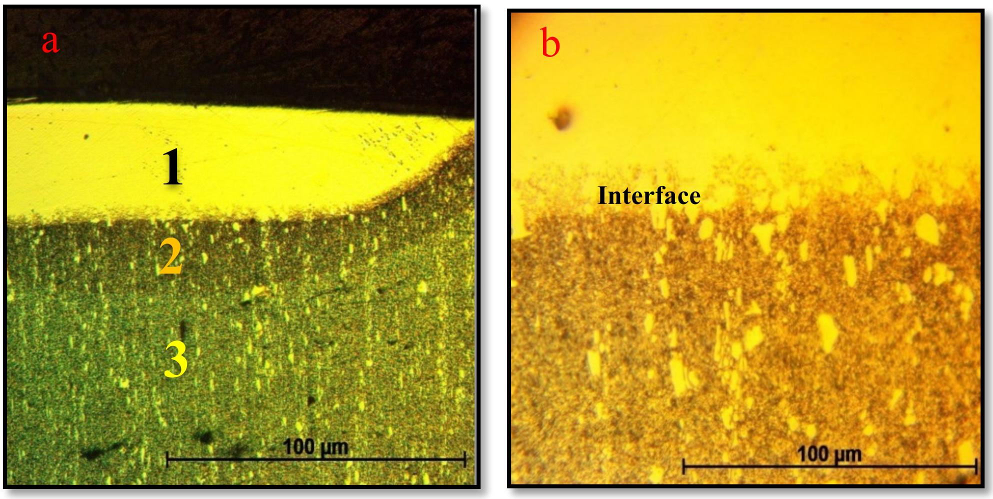

Fig. 4: Optical microscopy image of laser surface melting for X12 tool steel at 5.6mm/s scan speed, 12 HZ frequency, and 2mm defocus length. (a) 100X, (b) 200X

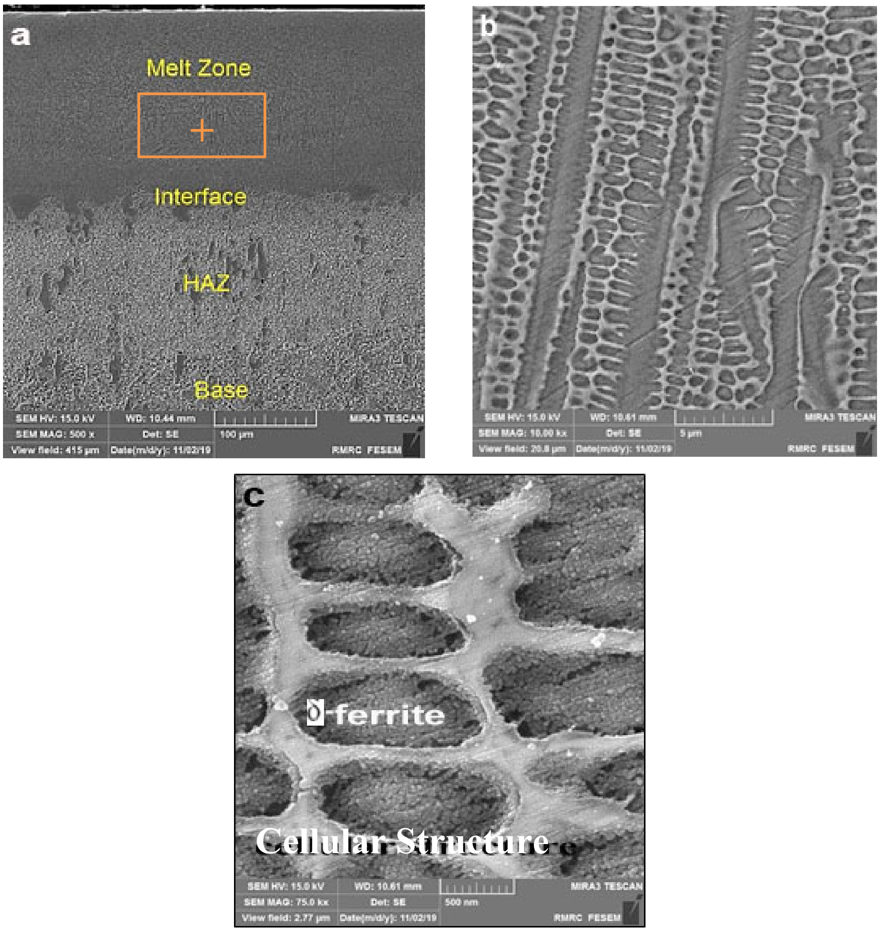

Fig. 5: Scanning electron microscopy analysis of laser surface re-melting cross-section of X12 tool steel at: (a) Low magnification, (b, and c) High magnification for a limited zone in (a)

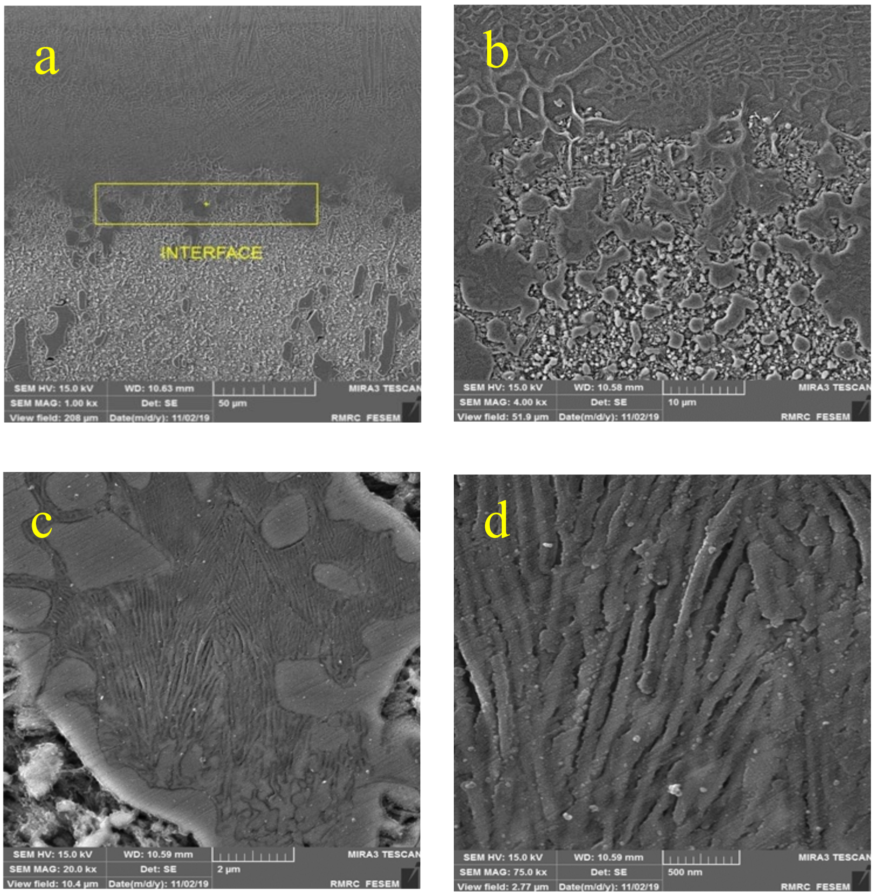

Fig. 6: Scanning electron microscopy of an interface between melt zone and HA Z in laser surface melting sample of X12 tool steel at, (a) Low magnification 50 µm, (b, c, d) High magnification force for a limited zone in (a)

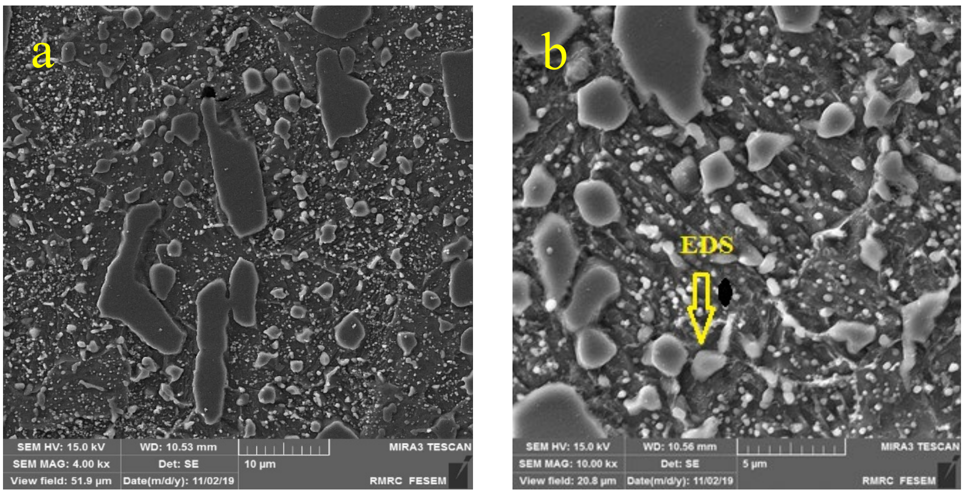

Fig. 7: Heat affected zone of X12 tool steel after laser surface re-melted in two magnification forces

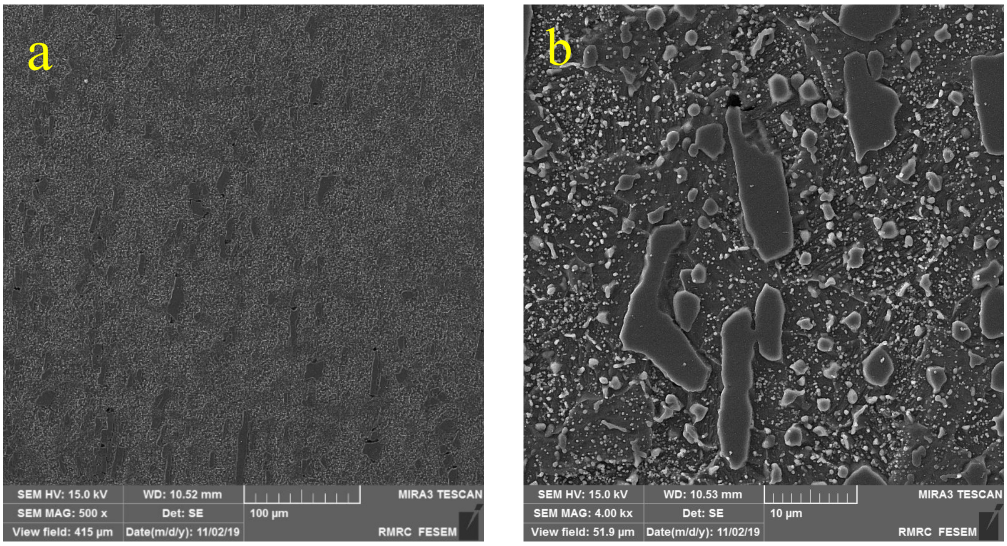

Fig. 8: Not affected (base alloy) zone of X12 tool steel after laser surface re-melting in two magnification forces

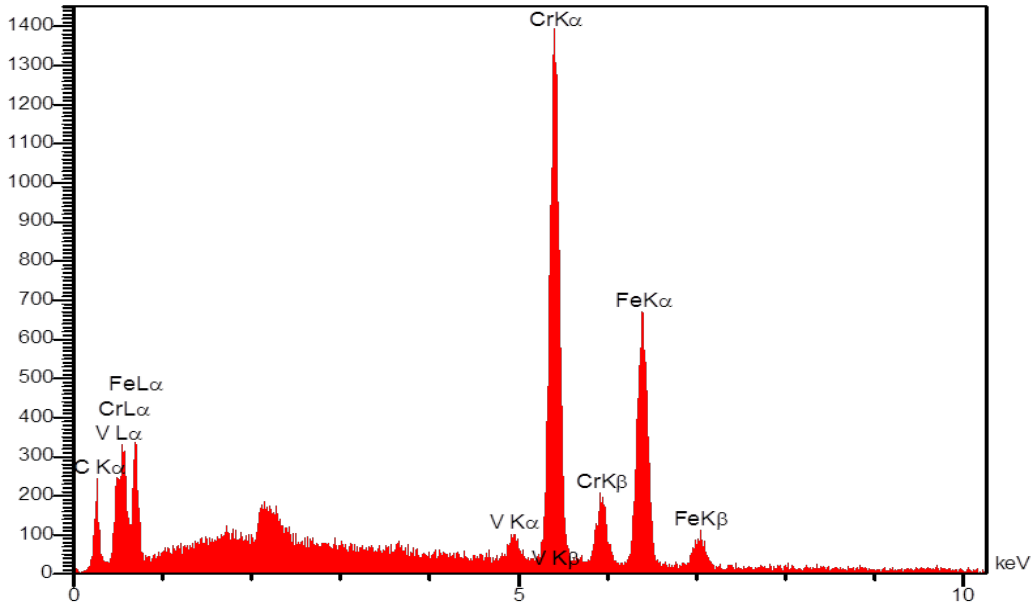

Fig. 9: EDS pattern of spot EDS in the heat-affected zone of X12 tool steel

Table 3: EDS analysis element and its ratios of spot EDS in the heat-affected zone of X12 tool steel

Elt	Line	Int	Error	K	Kr	W%
C	Ka	45.7	2.4268	0.0689	0.0584	17.37
V	Ka	25.6	0.9847	0.0199	0.0168	1.72
Cr	Ka	578.0	0.9847	0.5242	0.4440	44.50
Fe	Ka	296.2	0.9847	0.3870	0.3278	36.41

The presence of carbon, vanadium, chromium and iron are detected from the analysis of carbides. The elements V, Cr and Fe are strong affinity with carbon to form many forms of carbides. Fig.10- a, b shows the elemental analysis by EDS for line scan. It is clear that the chromium concentration is increase gradually to reach the highest value at the interface region.

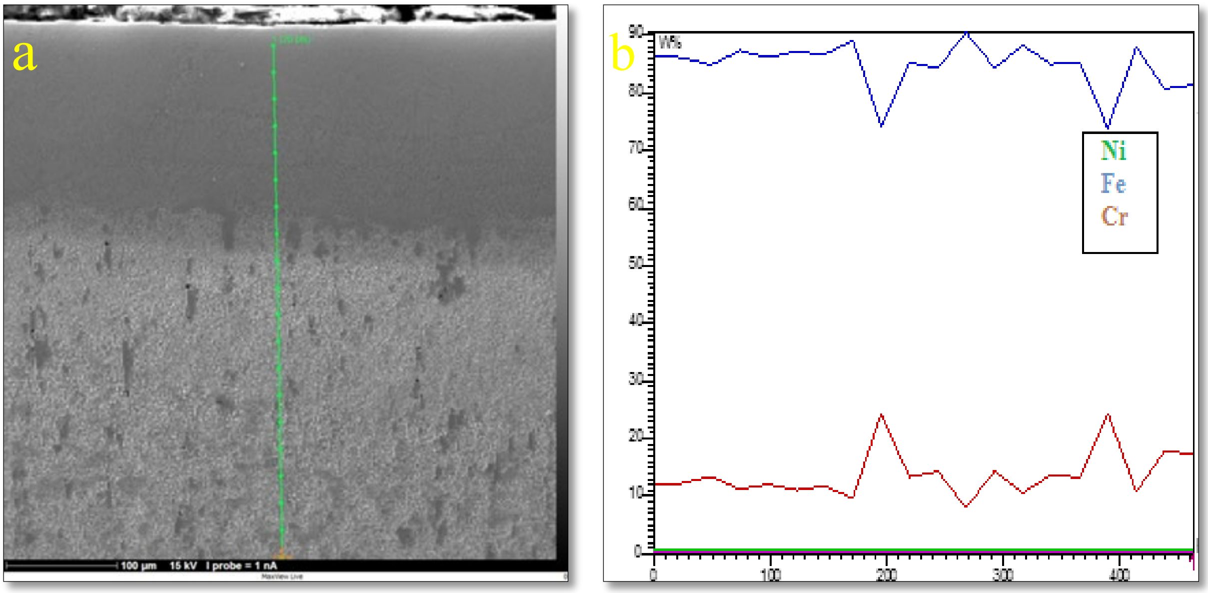

Fig. 10: Line EDS analysis of 20 points along different laser affected areas for the cross-section of laser surface melting X12 tool steel

Wear Behavior

Laser surface re-melting proved to have the smallest weight loss compared to the base material. Resulting values shows that wear resistance is improved by 74% after laser surface melting comparing with an as-received sample, see in Fig. 11. This is because of the refinement and the presence of fine particles of carbides Fe_3C, and $Cr_{23}C_6$ where these carbides provide more hardness.

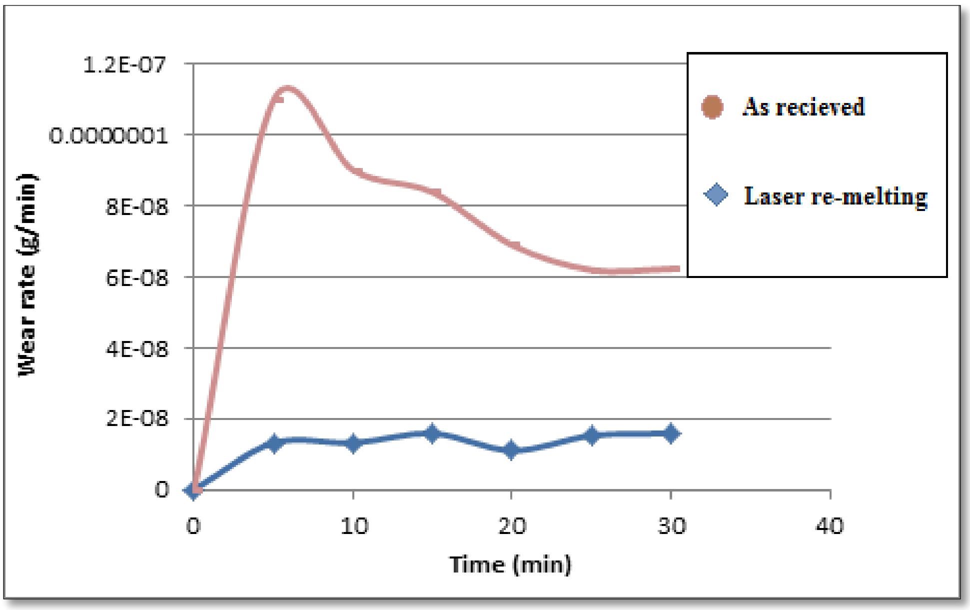

Fig. 11: Wear rate variation with time for laser surface melting, and as a received sample

Conclusions

1. Rapidly solidified layers of the surface X12 tool steel were obtained by Nd-YAG surface re-melting.
2. The main structure of the melted zone consists of cellular morphology with some of dendritic structure. Defects -free observed in melted zone.
3. Refinement in the microstructure and more uniform of carbides were obtained that caused by high cooling rate and high temperature gradient of laser process.
4. The were resistance of the re-melted zone of X12 steel and an improving in wear resistance of 74% higher than that of the as-received steel.

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