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Investigation of effect of various processing temperatures on abrasive wear behaviour of high power diode laser treated R260 grade rail steels

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ABSTRACT

This study is related to investigation of effect of different processing temperatures on tribological behaviours of high power diode laser treated samples. Laser treatment was applied to R260 grade rail steel specimens with the initial laser power of 1.750 W and a constant scanning speed of 6 mm/s at the different processing temperatures of 1.100 °C, 1.200 °C and 1.300 °C. As a conclusion 0.4, 0.56, 0.53 and 0.57 friction coefficient values were found for untreated and laser treated samples at 1.100 °C, 1.200 °C and 1.300 °C respectively. While it was expected that raise in surface hardness depending on increasing processing temperatures to result in reduction in wear rate and friction coefficient in laser treated samples, contrary an opposite situation in tribological behaviours was found.

1. Introduction

Wear problem is one of the important issues from the perspective of engineering applications. It leads to both loss of material and costs associated with grinding applications, replacement of material and downtime of the equipment. Because of this reasons, to minimize these costs and negations in terms of the technical point by increasing wear resistance of the materials is quite important [1].

The most important factors affecting wear are the chemical contents of the material and the hardness of the contact surfaces. Chemical content of the material can be changed during the manufacturing to get wear resistant material by adding some chemical elements such as carbon (C), silicon (Si), chrome (Cr) and wolfram (W). Surface treatment methods are used in order to increase surface hardness to increase wear resistance of contact surfaces.

Rails must be safety components in the railway system because of playing an important role in designating safeness and dependability of railway transport [2–5]. Main damages come out on the rail surface are wear, plastic deformation and rolling contact fatigue issues [6–9]. Wear is the main problem in the railway system because of the safety concerns. There are some maintenance works, such as grinding and re-profiling carried out in railway sector for worn rails. But these maintenance works reduce rail life and raise operational costs [10,11].

Maintenance and replacement of rails in railway network constitutes a significant part of total cost allocated for running. This situations do not only result in loss of time causing revenue loss but also waste of rail material which needs to be replaced due to a subsurface defect or a small defect on rail [12].

Continue rise in traffic density, axle tonnes and speeds on railway lines has required more stringent demands on rails in the world. Considering drivers making a contribution to the performance of railway superstructure components encompass toughness, residual stresses wear, fatigue and plastic deformation resistances [13–20]. Wear progression on rails and rail gauges are very important issues to be remedied by maintenance engineers. The wear problem also reveals different rail defects during a period of usage. So as to reuse and provide an ideal wheel-rail contact area these defects are regularly removed from the rail surface by grinding method and a considerable amount of money is spent for this improvement work. Instead of grinding method, rail lifetime extension can be provided by enhancing mechanical properties of rail steels. Especially, by providing a suitable surface treatment to the rails in small radiuses curves, rail sliding wear can be decreased a considerable extend and this situation contributes the extension of rail lifetime [21]. Formation of subsurface cracking is another problem encountered at rail gauge corners in common and in particularly this problem arises at small radiuses curves, cross and switches in a significant rate [22–24].

There are some studies recommending probable enhancements by using laser surface treatment methods such as laser cladding, laser melting/glazing and laser hardening by different sources [25–29]. Lewis at al [30] investigated the wear performance of different laser cladding

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materials which can be utilised to mend damaged rail. Effect of Al on microstructure and its impact on rail surface layer repair was studied by Li at al [31]. Furthermore, in another study [32] laser surface modification was studied and its effect on the mitigation of subsurface crack propagation in the rails were investigated. Both microstructure and wear resistance of laser cladding coatings were studied inclusively by Janne at al [33]. Chen at al [34] investigated the effect of wear behaviour of the laser quenched rail material. When looking at the studies [30–34], it is mentioned that surface modification with various laser applications has improved both mechanical properties of steel and wear behaviours.

Generally speaking conventional heat treatment methods, for instance flat-out hardening over water quenching, production of head hardened rails via thermal treatment processing etc. are used to increase mechanical behaviours of rails by reducing lamellar spacing which causes increased hardness resulting in enhanced rail lifetime [35–40]. Even though these conventional heat treatment methods are used in common, they encompass some drawbacks, for example a heat treated rail to be subjected huge warping over heat treatment process that is why some extra operations such as straightening and machining to be required and extra operations to cause extra time and money in a sense. On the contrary locally hardening can be provided by laser hardening methods with negligible warping [21].

When the working mechanism of laser hardening for steel materials is dealt with; a laser beam by a covetable spot size is used to scan surface of the material therefore temperature which is on the surface is augmented to the austenitisation range. This process doesn't require an additional cooling system, so a martensitic structure is obtained by the means of self-quenching due to high cooling rates.

Surface hardening by laser system has already been used in various engineering applications ranging from automotive sector to power generations and also there some studies for searching its applicability for railway components especially for rails but these studies are not enough and it necessitates more search in order to optimise the process to get much better results [32,41–43].

The current study is targeted at researching and comprehending the effect of various processing temperatures on abrasive wear behaviour of high power diode laser treated R260 grade rail steels. In this study, high power diode laser source with 3 kW maximum laser power was used to treat rail steel surfaces. Impact of process parameters on processing depths, hardness and microstructure was evaluated. Identification of different phases in treated and untreated of rail steel layers were carried out by XRD method. Abrasive wear tests were done utilising a pin on disc device under 5 N load in dry conditions for evaluating the wear behaviour of untreated and laser treated samples. SEM investigations and Surface Roughness tests according to the ISO 4287 standard [44] were carried out to understand the effect heat treatment on the surface and then results of the abrasive wear tests were discussed in detail.

2. Materials and method

In the scope of this study, R260 grade rail steel samples with 934 MPa tensile strength, 564 MPa yield strength 0,2% and 277 HV of surface hardness [43] was used and its chemical composition is given in Table 1.

Test samples of 10 mm thickness, 10 mm width and 55 mm length were prepared by using milling, wire erosion and metal cutting methods. All rail samples were ground to 0, 5 μm Ra roughness prior to laser hardening.

An 8 axis robotic system (ALOtec Dresden GmbH, Germany) having a laser beam spot size of 10 mm × 5 mm was utilised under an argon shield at 7 bar. High power diode laser was applied to rail steel surfaces over 20 s at the processing temperatures of 1.100 °C, 1.200 °C and 1.300 °C with the initial laser power of 1.750 W and a constant scanning speed of 6 mm/s.

Vickers hardness (HV) tests of laser treated and untreated samples were done by Zwick-ZHVμM hardness tester with the load of 0,5 kg and also PSW 30/15 model Mohr & Federhaff A.G. tester machine was used in order to carry out charpy impact tests of both laser treated and untreated specimens.

Abrasive wear tests were done in dry condition by Tribotech™ reciprocating wear tester with the test load of 5 N against Al_2O_3 ball having a diameter of 6 mm. Only the surface of the untreated sample was ground with 1.200 emery paper before the abrasive wear test. Laser treated samples were not ground in order not to damage to the treated layers. For all samples total sliding distance, sliding velocity and sliding stroke were set as 50.000 mm, 10 mm/s and 5 mm respectively. Abrasive wear experimental conditions are given in the following Table 2.

Friction coefficients were recorded over the test. After the tests, the wear volume loss of the treated and untreated samples were designated from 2-D profiles of the wear tracks that were attained by Veeco Dektak 6 M surface profillometer. By using volume loss and density, wear weight losses were also calculated for each sample depending on equation 3.1

$$\Delta V = \Delta G / \rho \tag{3.1}$$

Where;

ΔV: volume loss (cm^3), ΔG: weight loss (g), ρ: density (g/cm^3).

Phase analyses were carried out by X-Ray Diffraction (XRD). XRD analyses were conducted by PANalytical X'Pert PRO MPD X-Ray diffractometer with Cu Kα radiation between the angles of 10° – 120°.

In order to investigate laser treated surfaces rail steel samples were cleaned and SEM/EDS (JEOL JSM 5600) analyses were carried out.

Surface roughness tests were also carried out according to ISO 4287 standard [44] by Veeco Dektak 6 M surface profillometer device. General information about this device are; the country of origin is USA, stylus tip radius is 12,5 μm, scanning distance is 3.000 μm, contact force 3 mg and number of data points is 9.000.

Depending on the surface roughness test, Ra; arithmetic average of the absolute ordinate values throughout a sampling length, Rq; root mean square value of the ordinate values throughout a sampling length, Rv; largest profile valley depth throughout a sampling length, Rp; largest profile peak height throughout a sampling length, Rt; total of the height of the largest profile peak height and the largest profile valley depth throughout the evaluation length and Rz; total of height of the largest profile peak height and the largest profile valley depth throughout a sampling length values were measured.

3. Results and discussion

In the scope of hardness and charpy impact tests of both laser treated and untreated samples, obtained results are presented in Table 3a and b.

Table 2
Reciprocating wear test process conditions.

Load	5 N
Total Sliding Distance	50.000 mm
Sliding Stroke	5 mm
Abrasive Material	6 mm diameter alumina ball
Sliding Speed	10 mm/s
Room Temperature	24 °C ± 1
Rate of Humidity	% 35 ± 5

Table 1
Chemical composition of the used rail steel (wt. %).

C	Mn	Si	S	P	V	Cr	Ni	Cu	Mo	Al
0,71	1,05	0,37	0,010	0017	0,0028	0,028	0054	0,071	0038	0,0015