Proceedings of Asia International Conference on Tribology 2018, pp. 364-366, September 2018

Wear characterization of thick laser cladded high speed steel coatings

N. Ur Rahman[1,*], M.B. de Rooij[1], D.T.A. Matthews[1], G. Walmag[2], M. Sinnaeve[3], G.R.B.E. Römer[1]

[1)] Department of MS[3], Faculty of Engineering Technology, University of Twente,
Drienerlolaan 5, 7522 NB Enschede, The Netherlands.
[2)] CRM Group, Metal Processing Technology, Rue des Pôles 1, 4000 Liège, Belgium
[3)] Marichal Ketin, Rue Ernest Solvay 372, 4000 Liège, Belgium.

[*]Corresponding e-mail: n.naveedurrahman@utwente.nl

Keywords: Laser cladding; oxidative wear; carbide volume fraction

ABSTRACT – The wear behavior of three laser cladded high speed steel (HSS) alloys and one conventional spun cast HSS alloy was investigated by using a pin on disc tribometer at room temperature as well as at 500°C. Due to higher hardness and refined microstructure, laser cladded HSS alloys showed superior wear resistance and steady coefficient of friction at room temperature. But at 500°C, the casted HSS alloy showed the best wear resistance due to the rapid development of a stable oxide tribofilm. Among the laser cladded HSS alloys, the alloy with greater carbide volume fraction showed superior wear resistance at 500°C.

1. INTRODUCTION

High speed steel (HSS) alloys are key engineering materials showing an excellent combination of strength, hardness, wear and corrosion resistance [1]. Due to exceptional material properties, these alloys are used largely in variety of applications such as hot rolling, hot stamping, cutting tools and high speed machining [2]. Conventional casted HSS received greater attention, although these are composed of networks of coarser grain boundary carbides with grain size ranging from 20-200µm [3]. To improve the fatigue strength and crack propagation, further refinement of the microstructure is necessary which can be achieved by laser cladding process due to high cooling rates [4-5]. The laser cladding process is a manufacturing technique, which uses absorbed laser energy as a heat source to deposit clad layers of advanced properties onto the substrate [6].

In the past, limited work was done on the wear behaviour of laser cladded HSS coatings, further limiting these investigations to only thin deposits [7–9]. However Hashemi et al. investigated thick HSS deposits at various sliding speeds for the oxidative wear [3]. The current investigation addresses the wear characterization of thick HSS laser clads both at room temperature and at 500°C by taking into account the effect of oxidation.

2. EXPERIMENTAL

A CSEM high temperature pin on disc tribometer was used for friction and wear characterization of one spun cast HSS alloy and the three laser cladded HSS alloys. Laser cladding of HSS alloys was performed by using a 4.0 kW TRUMPF Nd:YAG laser source. Laser cladding was performed on $42CrMo_4$ cylindrical substrate of 50mm diameter. The maximum multilayer laser clad thickness was 20mm. Pins of 10mm diameter were machined from the casted and laser cladded HSS samples by a wire Electric Discharge Machine (EDM). Wear testing were performed at room temperature and at 500°C under a constant applied load of 5N for a sliding distance of 2000m. Low carbon steel discs of 50mm diameter were used as counter surface. The composition of major alloying elements of HSS alloys is listed in Table 1.

Table 1 Major alloying elements for HSS alloys (Wt.%).

Materials	Cr	V	W	Mo	Co
Cast HSS	4.5	4-6	-	5	-
LC1	4.3	3-5	5.6	4.6	-
LC2	4.1	3-5	5.6	4.6	3-5
LC3	4.3	3-5	4-7	4-6	-

A KEYENCE VHX-5000 optical microscope was used for the measurement of the wear diameter of pins. A JEOL JSM-7200 field emission Scanning Electron Microscope (SEM) equipped with Energy Dispersive X-ray Spectroscopy (EDS) sensors was used for microstructural and elemental analysis of the HSS alloys and the wear tracks. The wear rates were calculated from the volume loss of the pins based on the wear diameters [10–12].

3. RESULTS AND DISCUSSION

3.1 Microstructure and hardness

The microstructure of the spun cast HSS alloy consists of primary MC and eutectic M_2C carbides along with dark secondary precipitates of Vanadium rich carbides. For laser cladded HSS alloys, the microstructure consists of continuous network of fine eutectics of VC and M_2C carbides. While the refined martensitic matrix is enriched with $M_{23}C_6$ carbides along with the nano size secondary precipitates of complex carbides. In addition, LC2 contains 3-5% of Co which is homogenously distributed within the matrix. Addition of Co provides strength to the matrix at high temperature. SEM micrographs of four HSS alloys are shown in Figure 1 and micro hardness (HV) of these alloys is listed in Table 2.

Table 2 Micro hardness (HV0.5) of HSS alloys.

Materials	Hardness (HV0.5)
Cast HSS	660±10
LC1	710±15
LC2	780±10
LC3	810±12

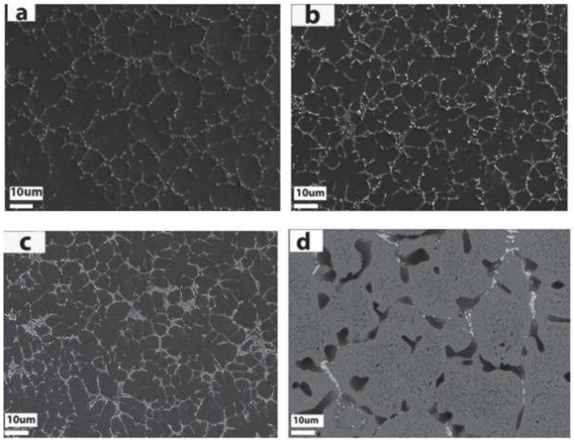

Figure 1 SEM micrographs (BSE) of (a) LC1 (b) LC2, (c) LC3 and (d) Cast HSS.

3.2 Friction and wear characterization

The mean coefficient of friction of cast HSS is slightly higher at room temperature (0.6 at 25°C) when compared to the laser clad HSS alloys (0.55 at 25°C), but at 500°C all four HSS alloys exhibited the same stable friction behaviour with a mean value of 0.6 as shown in Figure 2 for LC1.

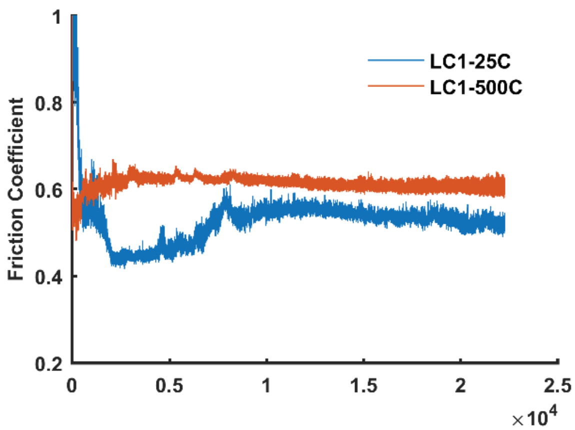

Figure 2 LC1 friction coefficient plots at 25°C & 500°C.

The cast HSS showed a higher wear rate at the 25°C as compared to the laser cladded HSS alloys, see Figure 3. The highly refined microstructure of laser cladded HSS alloys provided strength to the matrix to resist the abrasive wear (third body abrasion) which was dominant at room temperature. The highest wear rate of the cast HSS and the low values for laser cladded HSS alloys are justified by the lowest and highest hardness respectively.

Oxidative wear was the dominant wear mechanism at 500°C and third body abrasive particles combination of oxide & carbides debris, wore the matrix. Although carbides cracking was observed in the case of cast HSS but it still showed exceptional wear resistance as compared to the laser cladded HSS alloys at 500°C which is perhaps due to the formation of a very stable oxide layer on the matrix, see Figure 4. During the contact, larger carbides provided the mechanical support, i.e., load bearing capability, helping in the formation of the oxide layer on the matrix.

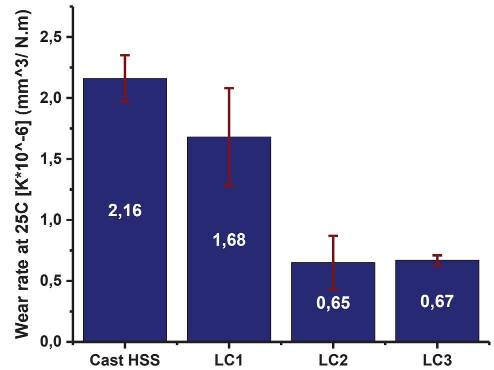

Figure 3. Wear rate of HSS alloys at 25°C.

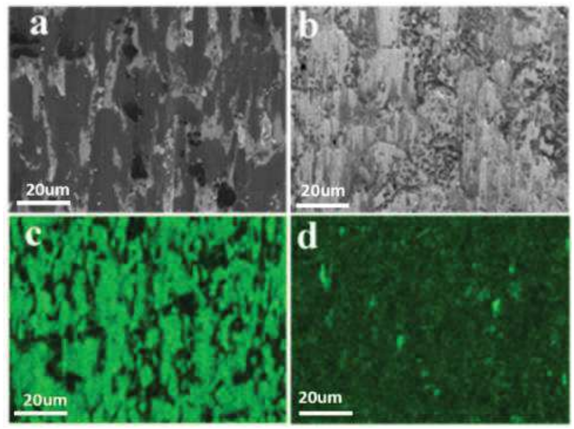

Figure 4 SEM and EDS plots of cast HSS (a & c) and LC1 (b & d) showing wear and oxidation respectively.

Due to the presence of $Cr_{23}C_6$ and complex nano carbides with in the matrices of LC1, LC2 and LC3, only partial oxidation is observed. As a result, the laser cladded HSS alloys showed poor wear resistance at 500°C and the matrix wore off due to the oxide and carbide debris. Discontinuous networks of M_2C carbides in laser cladded HSS alloys were easily peeled off due to poor anchorage, adding to the third body abrasion, see Figure 4. Among the laser cladded HSS alloys, LC3 showed improved wear resistance due to greater carbide volume percentage contributing to a higher average hardness. Presence of Co in the matrix of LC2, added no significance difference in the wear performance at 500°C.

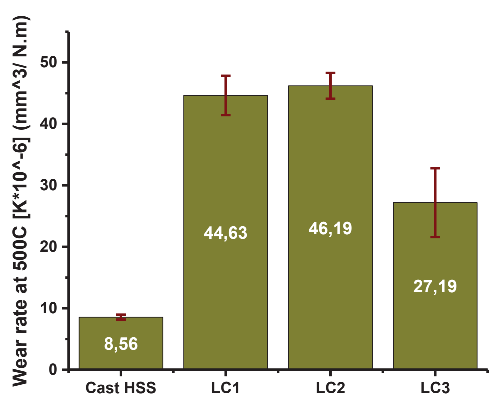

Figure 5 Wear rate of HSS alloys at 500°C.

4. CONCLUSIONS

(a) Highly refined microstructure of laser cladded HSS alloys reduced the abrasive contribution to wear at room temperature when compared to the cast HSS.

(b) Cast HSS showed greater wear resistance at 500°C than laser cladded HSS alloys due to rapid and stable oxidation of the matrix.

(c) For laser cladded HSS alloys, matrix was partially oxidized at 500°C due to the presence of Cr rich carbides and complex nano carbides with in the matrix.

(d) LC3 showed less wear at 500°C when compared to LC1 and LC2 due to higher carbide volume fraction.

ACKNOWLEDGMENT

This Project is funded by the European Research Fund for Coal and Steel (RFCS) under the grant agreement no. RFSR-CT-2015-00009.

REFERENCES

[1] Sun, G. F., Wang, K., Zhou, R., Feng, A. X., & Zhang, W. (2015). Effect of different heat-treatment temperatures on the laser cladded M3: 2 high-speed steel. *Materials & Design (1980-2015)*, *65*, 606-616.

[2] Niu, H. J., & Chang, I. T. H. (2000). Microstructural evolution during laser cladding of M2 high-speed steel. *Metallurgical and Materials Transactions A*, *31*(10), 2615-2625.

[3] Hashemi, N., Mertens, A., Montrieux, H. M., Tchuindjang, J. T., Dedry, O., Carrus, R., & Lecomte-Beckers, J. (2017). Oxidative wear behaviour of laser clad High Speed Steel thick deposits: Influence of sliding speed, carbide type and morphology. *Surface and Coatings Technology*, *315*, 519-529.

[4] Toyserkani, E., Khajepour, A., & Corbin, S. F. (2004). *Laser cladding*. CRC press.

[5] Mazumder, J., Schifferer, A., & Choi, J. (1999). Direct materials deposition: designed macro and microstructure. *Material Research Innovations*, *3*(3), 118-131.

[6] Farahmand, P., & Kovacevic, R. (2015). Corrosion and wear behavior of laser cladded Ni–WC coatings. *Surface and Coatings Technology*, *276*, 121-135.

[7] Tuominen, J., Näkki, J., Pajukoski, H., Hyvärinen, L., & Vuoristo, P. (2016). Microstructural and abrasion wear characteristics of laser-clad tool steel coatings. *Surface Engineering*, *32*(12), 923-933.

[8] Riza, S. H., Masood, S. H., & Wen, C. (2016). Wear behaviour of DMD-generated high-strength steels using multi-factor experiment design on a pin-on-disc apparatus. *The International Journal of Advanced Manufacturing Technology*, *87*(1-4), 461-477.

[9] Wang, S. H., Chen, J. Y., & Xue, L. (2006). A study of the abrasive wear behaviour of laser-clad tool steel coatings. *Surface and Coatings Technology*, *200*(11), 3446-3458.

[10] Rutherford, K. L., & Hutchings, I. M. (1996). A micro-abrasive wear test, with particular application to coated systems. *Surface and Coatings Technology*, *79*(1-3), 231-239.

[11] Archard, J. (1953). Contact and rubbing of flat surfaces. *Journal of Applied Physics*, *24*(8), 981-988.

[12] Hemmati, I., Ocelík, V., & De Hosson, J. T. M. (2011). The effect of cladding speed on phase constitution and properties of AISI 431 stainless steel laser deposited coatings. *Surface and Coatings Technology*, *205*(21-22), 5235-5239.