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Research Article

Experimental & Numerical Analysis of Steel Grades for Wear Resistance

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Abstract – This work examines the process of abrasive wear resistance of porous AISI D2 and H13 tool steels using Dry Sand Rubber Wheel (DSRW) tester for abrasion by the ASTM G65 standards. Different samples of hardness were subjected to various loads to check the wear performance. Findings show that D2 tool steel has superior wear resistance as compared to H13; due to its higher carbide content. The hardness was changed from 8 HRC to 62 HRC to formulate the D2 alloy for D2. The volume loss reduced significantly from 137.87 mm^3 to 58 mm^3 for the respective hardness which showed better wear resistance. In the same way, the specific wear rate of D2 reduced from 0.000246 mm^3/N-m to 0.0001 mm^3/N-m. By contrast, H13 steel exhibited increased volume loss on the rise of loading with specific wear rates that ranged between 0.000471 mm^3/N-m and 0.000519 mm^3/N-m. These results substantiate the fact that hardness is vitally important for wear resistance especially in case of D2 steel which makes it a better option for those applications that need high wear resistance in terms of abrasion.

Keywords – Abrasive wear resistance, DSRW, ASTM G65, D2 Steel, Hardness level

I. INTRODUCTION

This Wear is one of the key phenomena that influence the works and the life-time of the materials utilized in the industrial applications especially in the components which are subjected to the abrasive conditions [1]. Equipments operating in severe environments – for example equipment with dust, sand, and debris – wear extensively, degrading the material and causing a possible failure [2]. Therefore, it is crucial to assess the wear resistance of the materials that are used in such conditions to provide them with the durability and reliability [3]. Flow diagram is presented in fig 1.

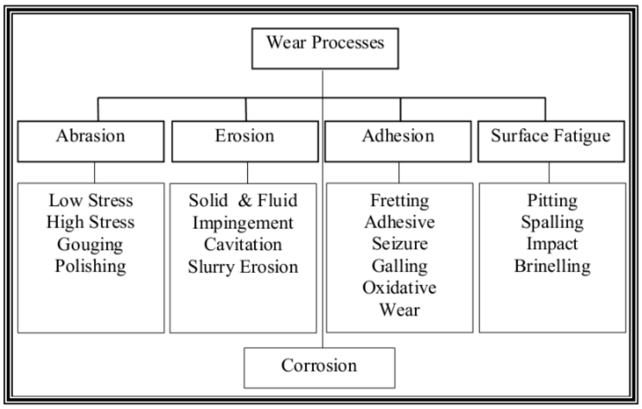

Fig. 1 Flow chart of various wear mechanisms

The dry sand/rubber wheel (DSRW) abrasion tester to ASTM G65 is an industrial and laboratory standard used for evaluating the engineering material abrasive wear resistance while ranking them [4] as depicted in fig 2. This equipment offers a reproducible technique to compare the wear behaviour of materials under conditions of control and is widely utilized in industries like mining, construction, and manufacturing to assess materials used in abrasive environments including shovels, draglines, die steels, agricultural implements, components of construction equipment and protective coatings [5].

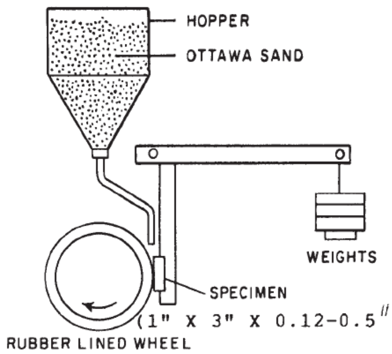

Fig. 2 Dry Sand Rubber Wheel Apparatus

For industries, this apparatus tends to run at a constant load and speed so as to maintain the same and comparable results of the test [6]. In this investigation, the abrasion tester of the DSRW type that is available in the Fracture Mechanics Laboratory will be used to research the wear resistance of high strength steels such as AISI D2 tool steel, AISI H13 tool steel and carbon steel [7]. D2 tool steel is useful in cold work applications due to the superiority trait of wear resistance in high-carbon high-chromium steel. [8]. H13 tool steel, on the other hand is a hot work tool steel, with 5% chromium and is good in terms of toughness and resistance to thermal fatigue and proves very suitable for uses which involve rapid heating and cooling cycles [9]. In this research, the DSRW abrasion tester available at the Fracture Mechanics Laboratory will be utilized to study the wear resistance of high-strength steels, specifically AISI D2 tool steel, AISI H13 tool steel, and carbon steel [7]. Cold work applications benefit from D2 tool steel because of its superior wear resistance trait in high-carbon high-chromium steel composition. [8]. H13 tool steel, on the other hand, is a hot work tool steel containing 5% chromium, offering good toughness and resistance to thermal fatigue, making it ideal for applications involving rapid heating and cooling cycles [9].The primary objective of this study is to investigate the wear resistance of these steel grades using the DSRW abrasion testing machine. Additionally, this research aims to establish a systematic procedure for evaluating abrasive wear resistance at different loads and hardness levels to understand their effects on wear performance [10]. Recent studies have highlighted the importance of microstructural characteristics, such as carbide distribution and grain refinement, in influencing the wear resistance of tool steels [11]. For instance, Baek et al. (2019) demonstrated that directed energy deposition could enhance the mechanical properties of tool steels by refining their microstructure [12]. Similarly, investigations into the wear behavior of additively manufactured H13 tool steel have shown that building direction and heat treatment significantly affect its wear properties [13]. This study will contribute to the selection of suitable materials for applications where wear resistance is crucial, supporting the development of robust materials for abrasive environments. The results will provide valuable data for optimizing material performance and improving the lifespan of components subjected to wear.

II. Literature Work

There are several researches conducted on the wear resistance of H13 and D2 tool steels through the use of the various enhancement methods. Kou et al. investigated the addition of TiC and TiB_2 nanoparticles to H13 tool steel, which led to a better uniformity of microstructure and wear resistance. Nonetheless, field-scale trials experimenting under industrial settings were not conducted in the study [14]. Likewise, Devi et al. studied the wear behavior of plasma-nitrided H13 and D2 steels, providing the two- to three-fold duration increase in the lifespan of the guide rolls. In spite of such benefits, the performance of the proprietary L7' steel deteriorated on account of substrate softening on nitriding temperatures and hence incapable of taking up wider commercial applications [15].

Zhang et al. tested cryogenic treatment on D2 tool steel and produced a better distribution of the carbide and more hardness, therefore increasing wear resistance; however, they did not investigate the economic feasibility [16]. Li et al. adopted laser surface melting in H13 steel, and gained finer microstructure and improved wear characteristics, although no long term durability was assessed [17]. Kim et al. (2018) used deep cryogenic treatment with tempering on D2 steel, contributing to the increase in wear resistance, but having no studies on the variation of parameters [18]. Singh et al. depict that the plasma nitriding followed by oxidizing the H13 created hard and lubricating layers, but only practiced standard parameters [19]. Garcia et al. optimized heat treatment for D2 steel to achieve wear resistance, but the findings were laboratory-based [20]. Chen et al. carried out SMAT on H13 steel improving wear resistance, scalability is however not mentioned [21]. Wang et al. reported vanadium enhanced wear resistance in H13 steel but was oblivious of cost implications [22]. Sathishkumar et al. used the method of electroless nickel coating on D2 steel enhancing the hardness of the surface but pay no attention to the adhesion strength in different loads [23].

Hassan et al. [24] carried out WEDM of D2 and DC53 steels where parameters for optimising surface finish were determined with the best results in D2 steel. However, wear resistance under real condition was disregarded. Mbakop Nanshie et al. [25] are dealt with the evaluation of tool steels in wood cutting using a 3D wear analysis. A8 steel containing 1% tungsten demonstrated best wear protection, while this one was better than others when it came to durability (W360). If apt for wood-cutting, industrial applicability on a wider scale was not evaluated.

III. MATERIAL AND METHOD

This The dry sand/rubber wheel abrasion test involves the abrading of a standard test specimen with an abrasive sand of controlled size and composition. The sand is introduced as an abrasive between the test specimen and a rotating wheel on which chlorobutyle rubber of a specified hardness is rimmed / molded. The test specimen is pressed against the rotating wheel at a specified force by means of a lever arm while a controlled flow of abrasive sand (300-400 gm/min) abrades the surface of test specimen. The test duration and force applied by the lever arm is varied according to the procedure adopted. Specimens are weighed before and after the test and the loss in mass recorded in grams. It is necessary to convert the mass loss to volume loss in cubic millimeters, by dividing it with density of test specimen. Abrasion is reported as volume loss in cubic millimeters per specified procedure. Wheel revolution counter counts the revolutions of the wheel and stop the drive motor after certain number of revolutions. Main components of the machine.

Rubber Wheel, Lever Arm, Specimen Holder, Sand Nozzle, Drive Motor, Wheel Revolution Counter, Sand hopper, Tachometer. As shown in figure 3.

Fig. 3 Manufactured dry sand/rubber wheel tester

The DSRW abrasion test measures the wear of material under controlled conditions in terms of critical factors. Applied load, time, sliding distance, sliding speed, and sand flow rate were used. Sand flow has to be laminar at 300–400 g/min, in order to provide even abrasion. Test time varies by procedure: A (30 min), B (10 min), C (30 sec), D (30 min), E (5 min). Linear abrasion distance is calculated by eqution 1.

$$Linear\ Sliding\ Distance\ (D)\pi d\ X\ N \tag{1}$$

The volume loss is calculated by equation 2:

$$Volume\ Loss\ (mm^3)\ = \frac{Mass\ Loss\ (kg)}{Desity\ of\ Specimen\ (kg/m3)} \times 10^9 \tag{2}$$

To account for wheel wear, adjusted volume loss is determined by equation 3:

$$\text{Adjusted Volume Loss (AVL)} = \text{Measured Volume Loss } (\text{mm}^3) \times \frac{228.6 \text{ mm}}{\text{Diameter after test}} \tag{3}$$

From volume loss we can calculate the wear rate of specimen which is defined as volume loss per unit abrading distance, mathematically it is expressed as equation 4

$$Wear\ Rate\ \left(\frac{mm^3}{m}\right) = \frac{Volume\ Loss}{Abrading\ Distance} \tag{4}$$

From this wear rate, specific wear rate can be calculated by using following expression.

$$Specific\ Wear\ Rate\ \left(\frac{mm^3}{N-m}\right) = \frac{Volume\ Loss}{Force \times Abrading\ Distance} \tag{5}$$

IV. Results and discussion

A research investigation tested the abrasive resistance of AISI D2 Tool Steel, AISI H13 Tool Steel, and Carbon Steel utilizing the Dry Sand/Rubber Wheel (DSRW) test method.

A. *Abrasive wear test*

The research adopted lawrancepur sand (density 2.6 g/cm3) as the abrasive material. The sand entered between the rotating rubber wheel and the test sample through the contacting face. The testing took place with a rotational speed set at 200 rpm. Abrasive feeding rate throughout the experiment amounted to 35 g/min. A cleaning process with acetone followed to dry the samples. The weight measurement was conducted in a high precision digital balance before the holder received the specimen. The test specimens received abrasives before installation between the rotating rubber wheel for testing purposes.

Table 1. Mechanical Properties of steels being tested

Material	Density (Kg/m3)	Tensile Strength (MPa)	Young's Modulus (GPa)	Yield Strength (MPa)	Bulk Modulus (GPa)	Shear Modulus (GPa)
AISI D2	7700	2380	210000	1950	140	80
AISI H13	7800	1990	210	1650	140	81

B. *D2 Steel Results*

The tests followed exact instructions from the Procedure. The study presents experimental findings for hardness, load, time, volume loss, wear rate, and specific wear rate in Table 2.

Table 2. Volume loss, wear rate, and specific wear rate of D2 Tool Steel

Specimen No.	Hardness (HRC)	Volume Loss (mm^3)	Wear Rate (mm^3/m)	Specific wear rate ($mm^3/N\text{-}m$)
D8	8	137.87	0.031996	0.000246
D7	51	65.11	0.015110	0.000116
D1	54	75.96	0.017628	0.000136
D3	62	58	0.012996	0.000100
D2	64	55.53	0.012887	0.000099

Table 2 describes the results obtained in terms of volume loss, wear rate, and specific wear rate. The analysis includes images of abraded D2 specimens in Fig 4

Fig. 4 Abraded surfaces of D2 specimens

C. *H13 Steel Results*

Table 3 describes the results obtained in terms of volume loss, wear rate, and specific wear rate for H13 tool steel specimens. Pictures of abraded H13 specimens are also shown in Fig 5. Fig 6 shows the graph between volume loss vs load, which indicates a direct relationship between load and volume loss means volume loss due to abrasion increases when load against specimen increases. Figure 7 shows the relationship between load and wear rate which indicates that wear rate increases with the increase in load.

Table 3. Volume loss, wear rate, and specific wear rate of H13 Tool Steel

Specimen No.	Load (N)	Hardness (HRC)	Volume Loss (mm^3)	Wear Rate (mm^3/m)	Specific wear rate ($mm^3/N\text{-}m$)
H1	65	51	145.405	0.033744	0.000519146
H2	130	51	263.91	0.061246	0.000471125

Fig. 5 Abraded surfaces of H13 specimens

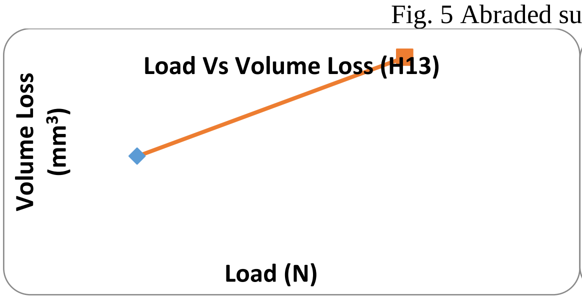

Fig. 6 Volume loss vs load for H13 specimens.

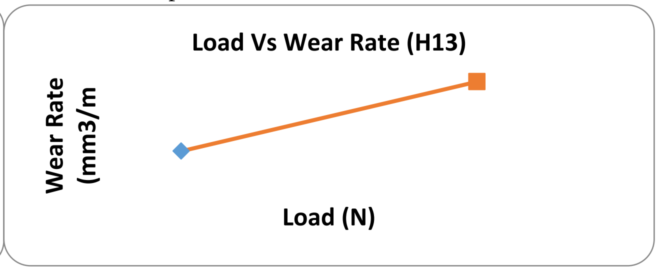

Fig. 7 Wear rate vs load for H13 specimens.

V. Conclusion and Future Work

Based on the results, several key conclusions can be drawn. Firstly, it is evident that hardness alone does not determine abrasion resistance. In some instances, such as with Specimens D8 and H1, annealed D2 steel with a relatively low hardness of 8 HRC outperformed H13 steel with a much higher hardness of 51 HRC. This enhanced wear resistance in D2 steel can be attributed to its high density of hard carbides, which effectively resist the penetration of abrasive sand particles. Microscopic examination of the abraded surfaces and microstructures supports this observation, showing that the absence of carbides in H13 steel leads to deeper gouging, whereas the presence of carbides in D2 steel results in discontinuous scratching, indicating better abrasion resistance. The DSRW abrasion tester used in this study was successfully manufactured and provided reliable results consistent with ASTM standards. Among the tested materials, D2 tool steel consistently demonstrated superior wear resistance compared to H13 tool steel, regardless of hardness level or applied load, with significantly lower volume loss. Additionally, the study found that an increase in the hardness of D2 steel directly enhances its wear resistance, further reducing volume

References

[1] Rajendhran, N., et al., Influence of abrasive characteristics on the wear micro-mechanisms of NbC and WC cermets during three-body abrasion. Wear, 2023. 530: p. 205007.

[2] Huang, X., et al., Wear of directed energy deposited H13 steel as a function of its graded microstructure. Tribology International, 2025. 207: p. 110617.

[3] Reichert, R.A., Amidst the Flow: Biographical Narratives, Social Trajectories, and Urban Itineraries of Crack Cocaine Users in São Paulo. 2024: Ethics International Press.

[4] Kannan, R., et al., Additive manufacturing as a processing route for steel-aluminum bimetallic structures. Materials & Design, 2023. 231: p. 112003.

[5] Omar, S.M.T.A., ADDITIVE MANUFACTURING OF AISI D2 TOOL STEEL USING DIRECTED ENERGY DEPOSITION. 2023, Dalhousie University.

[6] Johnsson, J., T. Tufvesson, and J. Costa, Characterization of D2 Tool Steel fabricated thru Fused Filament Fabrication Process. U. Porto Journal of Engineering, 2023. 9(3): p. 181-193.

[7] Haiko, O., Effect of microstructural characteristics and mechanical properties on the impact-abrasive and abrasive wear resistance of ultra-high strength steels. 2021.

[8] Karar, G.C., R. Kumar, and S. Chattopadhyaya, Developments on friction surfaced coatings for corrosion, wear-resistant and composite. Surface Engineering, 2025. 41(1): p. 8-24.

[9] Fonseca, E.B., et al., Fracture toughness and wear resistance of heat-treated H13 tool steel processed by laser powder bed fusion. Additive manufacturing, 2023. 78: p. 103862.

[10] Oliveira, A.P., et al., Effect of building direction and heat treatment on the wear behavior of H13 tool steel processed by laser powder bed fusion. Journal of Materials Research and Technology, 2024. 33: p. 9802-9810.

[11] Chaus, A., et al., Role of microstructural factor in wear resistance and cutting performance of high-speed steel end mills. Wear, 2021. 474: p. 203865.

[12] Devi, M.U., T. Chakraborty, and O. Mohanty, Wear behaviour of plasma nitrided tool steels. Surface and Coatings Technology, 1999. 116: p. 212-221.

[13] Zhang, C., et al., Understanding of the Microstructure Evolution and Wear Resistance of Cr12MoV Die Steel during Deep Cryogenic Treatment. Journal of Materials Engineering and Performance, 2024: p. 1-12.

[14] Meng, C., et al., Effect of thermal fatigue on microstructure and mechanical properties of H13 tool steel processed by selective laser surface melting. Metals, 2019. 9(7): p. 773.

[15] Kim, K.-H., et al., Microstructure and fracture toughness of nitrided D2 steels using potential-controlled nitriding. Metals, 2022. 12(1): p. 139.

[16] Lanzutti, A. and E. Marin, The challenges and advances in recycling/re-using powder for metal 3D printing: A comprehensive review. Metals, 2024. 14(8): p. 886.

[17] Félix-Martínez, C., et al., Microstructure, hardness, and tribological performance of D2 tool steel fabricated by laser cladding using pulsed wave and substrate heating. Optics & Laser Technology, 2024. 175: p. 110862.

[18] Liu, B., et al., Thermal fatigue evaluation of AISI H13 steels surface modified by gas nitriding with pre-and post-shot peening. Applied Surface Science, 2019. 483: p. 45-51.

[19] Wang, H., et al., Effect of Rare Earth Oxide-Containing Slag on the Formation of Inclusions and Carbides in H13 Tool Steel: Analyses of Slag-Steel Reactions and Their Thermodynamics. Metallurgical and Materials Transactions B, 2025: p. 1-16.

[20] Dash, L., et al., Machinability investigation and sustainability assessment in hard turning of AISI D3 steel with coated carbide tool under nanofluid minimum quantity lubrication-cooling condition. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 2021. 235(22): p. 6496-6528.

[21] Arslan, Y., I. Uygur, and A. Jazdzewska, The effect of cryogenic treatment on microstructure and mechanical response of AISI D3 tool steel punches. Journal of Manufacturing Science and Engineering, 2015. 137(3): p. 034501.

[22] Shi, Q., Recycling of titanium alloys from machining chips using equal channel angular pressing. 2015, Loughborough University.

[23] Raja, S.B., 2.5 Optimization with Surface Roughness as Objective Function.

[24] Hassan, S., et al., Parametric analysis and multi-objective optimization for machining complex features on D2 and DC53 steels for tooling applications. Journal of Materials Engineering and Performance, 2024: p. 1-15.

[25] Mbakop Nanshie, V., et al., Impact of coating and microstructure on wear resistance of tool steels for wood cutting: a novel approach to quantification and analysis of wear-related damages. Journal of Wood Science, 2024. 70(1): p. 20.