Review Article **ISSN 2771-666X**

Journal of Advanced Materials Science and Engineering

Influence of Various Parameters on Wear Resistance

Saidi Jaouhar[1]* and Briki Jalel[2]

[1]*National Engineers School of Tunis, Tunisia.*

[2]*Professor at ENIT.*

***Correspondence:**
Saidi Jaouhar, National Engineers School of Tunis, Tunisia.

Received: 09 Aug 2023; **Accepted:** 12 Sep 2023; **Published:** 18 Sep 2023

Citation: jaouhar S, jalel B. Influence of Various Parameters on Wear Resistance. J Adv Mater Sci Eng. 2023; 3(1): 1-6.

Introduction

Wear resistance is a critical property in various industrial applications where materials are subjected to abrasive forces. Understanding and enhancing wear resistance have been the focus of extensive research. In this study, we investigate the influence of various parameters on the wear resistance of materials. The abrasion wear test, utilizing a three-body abrasion approach, has been employed as a method to assess wear resistance. This method involves subjecting test specimens to rotational and sliding forces against a polishing disc in the presence of slurry. However, the measurement based on mass loss can pose limitations, particularly when applied to thin coatings. An alternative three-body test approach has been proposed by Smith and Chung, involving lubrication-free abrasion to minimize third-body effects. Despite these efforts, challenges in achieving repeatability and reproducibility persist. In this study, we aim to systematically explore the impact of various parameters on wear resistance, shedding light on the complex interplay between material properties, test conditions, and wear behavior.

Fatigue Behavior

A three-body abrasion wear test, which was applied by Axen et al. [1] and Axen and Jacobson [2] to a range of soft metals, polymers, and soft matrix composites, employs a commercial polishing machine, StruersAbrapol. Spindles of the sample material are loaded and rotated against a rotating polishing disc in the presence of slurry. However, since wear measurement is based on mass loss, the method presents disadvantages when applied to thin coatings [3]. Another approach to the three-body test was suggested by Smith and Chung [4], who used an unlubricated Taber Abraser so that third-body particles became separated from the abrasive wheels and remained within the wear track. Nonetheless, given that the ASTM description of the standard version of this test warns of poor repeatability and reproducibility [5], a test that further relies on an uncontrollable degree of particle detachment should exhibit even worse repeatability.

Relatively few studies have examined the performance of coated tools at high temperatures. This is of interest to industries such as die casting and hot forging, where tool materials need to possess high toughness, elevated yield strength, and the ability to withstand erosion, wear, and thermal fatigue. A study on the performance of AISI H13 tool steel, coated with TiN and CrN coatings, was conducted through thermal fatigue tests on a thermal cycling bench. Cylinders measuring 20 mm in length and 10 mm in diameter were subjected to 500 cycles of high-frequency induction heating and water cooling, with respective durations of 7 and 3 seconds. Thermal fatigue damage was assessed by analyzing different crack dimensions and distributions using optical microscopy. The results demonstrated that the coatings enhanced thermal fatigue resistance. Various metal forming processes are carried out at temperatures exceeding 0.5 times the homologous temperature and are thus considered as hot work. These include die casting, continuous casting, hot forging, and extrusion. During hot work, tools and dies experience thermal gradients. The core is kept cooler than the surface. Heat flows from the work material to the die, heating the surface during their contact period, while the entire die cools down during part withdrawal. These thermal gradients lead to dimensional variations that generate stresses and deformation.

The Malm and Norstrom model suggests that materials with high resistance to thermal fatigue should have a low coefficient of thermal expansion, a low Poisson's ratio, and a high yield strength/elastic modulus ratio [6]. Oxidation resistance [7] and residual compressive stress [8] also contribute to increasing thermal fatigue resistance. Certain properties and characteristics of hard coatings TiN and CrN suggest that they can enhance the thermal fatigue resistance of a typical hot work steel. The higher chemical inertness of the coatings and the high residual compressive stresses, when produced through physical vapor deposition (PVD), should also aid in this aspect. The combination of ion nitriding and hard coating can further increase thermal fatigue resistance as it provides better mechanical support to the hard coating than tool steel alone. The nitriding layer also increases material depth with compressive stress [9], thus likely improving thermal fatigue resistance. There are few articles on the thermal fatigue behavior of hard coatings. This article examines the damage caused by thermal cycling of AISI H13 hot work tool steel in four conditions: uncoated, TiN-coated, CrN-coated, and duplex-coated (nitrided plus TiN).

The utilized hard coatings can inhibit thermal fatigue. The mechanism has not yet been fully disclosed, but it is likely to involve both a delay in nucleation and growth of cracks due to the high hot hardness of the coating and the elevated residual compressive stress. This effect, coupled with the high hardness of the coatings that reduces wear, can contribute to extending the lifespan of the die during hot work. A nitrided layer between the TiN coating and the tool steel can further enhance resistance to low-cycle fatigue [10].

Effect of Manufacturing Method (PM)

The advantages of the powder metallurgy (PM) route as a means of producing high-performance steels, compared to traditional production methods such as melting, casting, and hot extrusion, are most evident in high-speed steels (HSS) for tooling. Due to the finer and more uniform microstructure exhibited by PM-HSS, in contrast to their conventionally produced counterparts, they also offer improved cross-sectional hardness uniformity (wear resistance), fracture toughness, and fatigue resistance—all relevant properties in cutting tool design.

Regarding the mechanical properties of PM-HSS, in contrast to the information available for hardness, strength, or toughness [11], there is relatively limited existing data on fatigue behavior. Concerning fatigue characteristics, only a few studies have been reported in the literature [12-14], primarily focusing on fatigue life assessment and corresponding fractographic characterization. From these studies, it is now well established that (1) PM-HSS exhibit significantly enhanced fatigue resistance compared to conventionally produced HSS; and (2) fatigue failure in PM-HSS is attributed to the propagation of cracks initiated at intrinsic processing defects, namely internal inclusions, carbides, or pores. This experimental finding is employed here as a premise to estimate conditions of "infinite" life based on a sub-critical crack growth threshold. In doing so, the fracture and fatigue behavior of PM-HSS is meticulously documented and analyzed within the framework of Linear Elastic Fracture Mechanics (LEFM). The intended approach is then implemented by (1) defining the critical flaw size under cyclic loading in terms of the fatigue crack growth (FCG) threshold and (2) assuming a similarity in FCG behavior characterization across LEFM parameters for both large cracks and small natural flaw defects.

Based on the well-established fact that the fatigue life of powder metallurgy-derived high-speed steels (PM-HSS) is governed by sub-critical crack growth of pre-existing flaws, a Linear Elastic Fracture Mechanics (LEFM) approach is employed to evaluate a fatigue limit – Correlation of Fatigue Crack Growth (FCG) threshold under conditions of infinite life. In doing so, the critical flaw size under cyclic loading is simply defined in terms of the FCG threshold. Furthermore, it is assumed that the fundamental LEFM correlation between flaw size, strength, and threshold conditions evaluated for large cracks also applies to natural flaws. As a result, the fatigue limit value for the studied PM-HSS is predicted using experimentally measured fracture and FCG characteristics, provided that critical flaws are similar in terms of nature, geometry, and size under both monotonic and cyclic loading. The reliability of the applied LEFM approach is supported by the excellent agreement observed between estimated and experimentally determined fatigue limit values [17].

The fracture and fatigue characteristics of fine-grained PM-HSS were investigated, with a specific focus on evaluating an FCG-fatigue life correlation within a LEFM framework. It is indicated that the fatigue behavior of PM-HSS can be rationalized, under conditions of infinite life, by considering: (1) Sub-critical growth of pre-existing flaws as the dominant step in fatigue life behavior; hence, FCG threshold as the effective toughness under cyclic loading; (2) Similarity in FCG behavior characterization across LEFM parameters for both large cracks and small natural flaws; (3) Consistency of flaw strength controlling defects of the same type, geometry, size, and distribution under both monotonic and cyclic loading. The implementation of this threshold-based approach is validated through the excellent agreement found between estimated and experimentally determined fatigue limit values [15].

The dynamic pace of technology and engineering development, as well as ongoing research into new technological solutions, pertains to both manufactured products and the tools used in their manufacturing and forming processes [16,17]. The growth of competitiveness among tool material manufacturers and the high demands from buyers, driven by improved functional parameters of machinery and equipment, undoubtedly contribute to the reason why numerous scientific and research centers are engaged in research aimed at enhancing working properties and reducing manufacturing costs of tool materials. High-speed steels belong to the group of relatively well-studied materials. Tools made from them are used for heavy-duty work, imposing high functional requirements. Research efforts thus far to meet these demands and extend their lifespan have primarily focused on optimizing their chemical composition, coating, and manufacturing using powder metallurgy to eliminate the segregation of primary carbides, a characteristic of steels produced using conventional methods. Modern manufacturing technologies, including powder injection molding and pressureless forming [16-21], aim to maximize the use of input materials and sinter tools to their final shapes, thereby eliminating costly plastic forming and machining, leaving only final grinding. Despite the significant interest of many research centers in new manufacturing technologies for high-speed steels, it is noted that only a few of them address heat treatment issues and functional properties of these materials in the as-quenched and tempered state, limiting the scope of their work to determining optimal sintering temperature and phase transformations occurring solely during the process [18-21].

The introduction of nitrogen into steel during its sintering in protective gas atmospheres with nitrogen is intriguing due to its potential for improving abrasion wear resistance. The sintering process in protective gas atmospheres is not as common as vacuum sintering due to the need for higher sintering temperatures and a narrow sintering window, as nitrogen raises the solidus temperature [22,23]. The MX-type carbonitrides formed during sintering are stable at high austenitization temperatures and abrasion-resistant. Furthermore, they do not coagulate or grow at a rate like M6C-type carbides, and they are uniformly distributed in the high sintering temperature ferrite alloy matrix. The investigations carried out in this study reveal that experimental high-speed steels of types HS6-5-2 and HS12-1-5-5 formed without pressure from a polymer powder suspension and subjected to heat treatment exhibit high abrasion wear resistance. These steels can become austenitic at a lower temperature compared to commercial steels, owing to the high carbon concentration remaining after binder degradation, which lowers the solidus temperature. Tribological tests on the experimental steels confirm the merit of using pressureless-formed high-speed steel from the polymer powder suspension, particularly when sintered in an N2–5% H2 protective gas atmosphere, which promotes nitrogen diffusion and the development of fine MX-type carbonitrides, thereby enhancing abrasion wear resistance. The experimental HS12-1-5-5 grade steel produced by pressureless forming from the polymer powder suspension, with material removal volumes of approximately 0.01 and 0.005 mm3 in pin-on-disk and pin-on-plate tests respectively, is characterized by the highest abrasion wear resistance [24].

Effect of Carbon Content

The effects of carbon content on the microstructures : mechanical properties, and wear behavior of high-vanadium high-speed steel (10% vanadium) have been systematically studied. The results demonstrate that carbides in the high-vanadium high-speed steel consist of vanadium carbide, a small amount of composite chromium carbide, and composite molybdenum carbide. With increasing carbon content, the quantity of carbides increases significantly, and the carbide morphology changes from rod-like and banded to more massive and spherical forms. Simultaneously, the microstructures of the metallic matrix transform from ferrite, ferrite mixture, martensite, and retained austenite to retained martensite and austenite. The hardness and wear resistance of the high-vanadium high-speed steel are enhanced, but its impact toughness could be reduced. Given the rapid development of the industry, traditional alloy steel rollers and composite rollers with a high-chromium cast iron wear layer [25-27] face challenges in meeting the demands for roller lifespan. Effect of Carbon Content; The effects of carbon content on the microstructures, mechanical properties, and wear behavior of high-vanadium high-speed steel (10% vanadium) have been systematically studied. The results demonstrate that carbides in the high-vanadium high-speed steel consist of vanadium carbide, a small amount of composite chromium carbide, and composite molybdenum carbide. With increasing carbon content, the quantity of carbides increases significantly, and the carbide morphology changes from rod-like and banded to more massive and spherical forms. Simultaneously, the microstructures of the metallic matrix transform from ferrite, ferrite mixture, martensite, and retained austenite to retained martensite and austenite. The hardness and wear resistance of the high-vanadium high-speed steel are enhanced, but its impact toughness could be reduced. Given the rapid development of the industry, traditional alloy steel rollers and composite rollers with a high-chromium cast iron wear layer [25-27] face challenges in meeting the demands for roller lifespan. Effect of Carbon Content; The effects of carbon content on the microstructures, mechanical properties, and wear behavior of high-vanadium high-speed steel (10% vanadium) have been systematically studied. The results demonstrate that carbides in the high-vanadium high-speed steel consist of vanadium carbide, a small amount of composite chromium carbide, and composite molybdenum carbide. With increasing carbon content, the quantity of carbides increases significantly, and the carbide morphology changes from rod-like and banded to more massive and spherical forms. Simultaneously, the microstructures of the metallic matrix transform from ferrite, ferrite mixture, martensite, and retained austenite to retained martensite and austenite. The hardness and wear resistance of the high-vanadium high-speed steel are enhanced, but its impact toughness could be reduced. Given the rapid development of the industry, traditional alloy steel rollers and composite rollers with a high-chromium cast iron wear layer [25-27] face challenges in meeting the demands for roller lifespan. Effect of Carbon Content; The effects of carbon content on the microstructures, mechanical properties, and wear behavior of high-vanadium high-speed steel (10% vanadium) have been systematically studied. The results demonstrate that carbides in the high-vanadium high-speed steel consist of vanadium carbide, a small amount of composite chromium carbide, and composite molybdenum carbide. With increasing carbon content, the quantity of carbides increases significantly, and the carbide morphology changes from rod-like and banded to more massive and spherical forms. Simultaneously, the microstructures of the metallic matrix transform from ferrite, ferrite mixture, martensite, and retained austenite to retained martensite and austenite. The hardness and wear resistance of the high-vanadium high-speed steel are enhanced, but its impact toughness could be reduced. Given the rapid development of the industry, traditional alloy steel rollers and composite rollers with a high-chromium cast iron wear layer [25-27] face challenges in meeting the demands for roller lifespan.

Therefore, the search and development of wear materials with even better properties have been pursued [28-32]. Preliminary research has shown that the lifespan of high-vanadium steel rollers is five times longer than that of high-chromium cast iron rollers [33,34]. Meanwhile, the lifespans of crusher hammers and jaws, made from high-speed steels intended for use in the crushing industry, are three times and 10 times longer than those of high-chromium cast iron and high-manganese steel, respectively [35,36]. High-vanadium high-speed steel has emerged as an ideal wear material with excellent properties and can be used to replace high-chromium cast iron. For high-vanadium high-speed steel, the quantity of vanadium and other alloying elements is fixed in its compositions, but the amount of carbon varies. It directly influences not only the formation of carbides but also the microstructures of the matrix, the hardness, impact resistance, and wear properties of high-vanadium high-speed steel, among other factors. In order to promote its industrial application, the effects of carbon on the microstructures and properties of high-vanadium high-speed steel have been systematically studied.

The pin-on-disk test belongs to the stationary two-body abrasive wear category, where the predominant wear mechanism is micro-cutting [37,38]. In this mechanism, the wear weight loss (wear resistance) of materials depends on their hardness. Consequently, as the carbon content increases, the hardness of the tested materials also increases, leading to a decrease in their wear weight loss, meaning their relative wear resistance increases. However, when the carbon content exceeds 2.25%, the increase in material hardness becomes gradual, resulting in a slower decrease in wear weight loss, thus indicating a slower increase in wear resistance [39].

Effects of Heat Treatment; Wear has been defined as the removal of material from solid surfaces, which can lead to the failure of industrial components [40]. Numerous investigations into wear modes have been conducted by various researchers over the years [41-43]. The wear mechanisms and wear rates are heavily dependent on chemical composition [44], microstructure, load conditions [45], and surface properties of the materials.

The wear modes of steels are either oxidative or mild. At low load levels, severe wear occurs shortly after the onset of sliding, with the formation of large metallic wear debris leading to a high wear rate. Subsequently, the wear mode transitions to a stable mild state with fine oxidized wear debris [45]. Conversely, at high loads, the contact temperature is increased. This temperature can exceed 400°C [42] if the sliding speed and contact pressure are sufficiently high. This high-temperature condition may indicate oxidative wear of steels [43]. In general, the martensitic phase transformation is commonly employed to enhance the wear resistance of steels [46]. However, numerous components with a ferrous martensitic structure fail unexpectedly, and their failures are often attributed to wear [40,46]. Hence, the volumetric fraction of the martensitic phase not only significantly influences the lifespan of industrial component surfaces but can also have contrasting effects under certain conditions.

The effects of conventional heat treatment on the wear resistance of AISI H13 tool steel were investigated. A pin-on-disk setup at a speed of 0.07 m/s with two loads of 29.4 and 98 N was employed to study wear behavior. In order to comprehend the wear mechanisms, wear tracks and debris were examined using scanning electron microscopy and X-ray methods. Furthermore, the depth of the hardened zone beneath the wear tracks and the friction behavior of AISI H13 tool steel were assessed. Experimental results reveal that under a 29.4 N load, the quenched specimens exhibit the highest wear resistance, and the debris consists of a mixture of oxide and plate-like metallic powders. On the other hand, at a 98 N load level, specimens quenched for 30 to 60 minutes at 600°C demonstrate the highest wear resistance, and the wear mode is oxidative [47].

From the results obtained under the experimental conditions of this study, the following conclusions can be drawn: At the lower load level of 29.4 N, specimens with a martensitic structure exhibit the highest wear resistance, and the wear mode is mild, characterized by fine oxide particles and plate-like metallic fragments in the debris. At a higher load level of 98 N, specimens quenched for 30 to 60 minutes demonstrate the highest wear resistance. The wear mode is oxidative, resulting in rounded and agglomerated oxide particles in the debris. At the elevated load of 98 N, the friction surface temperature is sufficient for an in-situ surface tempering process, potentially leading to a transformation from a martensitic to a tempered-soft structure. At the lower load of 29.4 N, due to lower local pressure and temperature, there is no in-situ surface tempering. Work hardening is observed at the subsurface level, and the depth of the hardened zone increases with applied load. The gradual increase in friction coefficient at a load of 98 N can be attributed to the phenomenon of in-situ surface tempering.

Conclusion

The wear resistance of materials is influenced by a variety of parameters, including fatigue, metallurgy, and the presence of powder and carbon. Let's break down the effects of these parameters on wear resistance:

Fatigue

Fatigue refers to the weakening of a material due to cyclic loading or repeated stress cycles. Fatigue can significantly affect wear resistance by causing microcracks, surface deformations, and material degradation. When a material undergoes cyclic loading, it becomes more susceptible to wear because cracks can propagate and accelerate wear processes. In essence, fatigue reduces the material's ability to withstand wear over time.

Metallurgy

The metallurgical composition of a material has a profound impact on its wear resistance. Different alloys and heat treatments can lead to variations in hardness, toughness, and microstructure. Hardness is a key factor in wear resistance; harder materials tend to have better wear resistance as they can withstand abrasive forces and deformation. However, an overly brittle material may experience cracking and failure under severe wear conditions. The microstructure also plays a role in wear resistance, with finer grain structures often exhibiting improved wear resistance due to reduced defect propagation.

Presence of Powder and Carbon

The presence of powder and carbon can affect wear resistance in several ways. Adding powder particles or carbonaceous materials to a matrix can alter the material's mechanical properties. For example, adding hard particles can increase hardness and resistance to abrasive wear, while carbon-based additives might enhance lubricity and reduce friction. However, the dispersion and adhesion of these additives within the material matrix are crucial. Poor distribution can lead to localized wear and reduced overall wear resistance. It's important to note that wear resistance is often evaluated through various testing methods, such as pin-on-disk tests, wear tests under different loads and speeds, and abrasive wear tests. These tests help quantify the effects of different parameters on wear behavior.

Optimizing wear resistance requires a comprehensive approach, considering factors like material selection, heat treatment, alloy composition, reinforcement materials, and testing conditions. Engineering materials with superior wear resistance involves a balance between hardness, toughness, microstructure, and the ability to resist fatigue and surface damage.

References

1. Axen N, Jacobson S, Hogmark S. Influence of hardness of the counterbody in three-body abrasive wear - an over looked hardness effect. Tribol. Int. 1994; 27: 233-241.
2. Axen N, Jacobson S. A model for the abrasive wear resistance of multiphase materials. Wear. 1994; 174: 187-199.
3. Hutchings IM. Abrasive and erosive wear tests for thin coatings: a unified approach. in: Hutchings Ed. New Directions in. Tribology, Mechanical Engineering Publications, Bury St. published in Tribol. Int. 1998; 31: 5-15.
4. Smith AV, Chung DDL. Titanium diboride particle-reinforced aluminium with high wear resistance. J. Mater. Sci. 1996; 31: 5961-5973.
5. ASTM D4060, Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser. in Annual Book of ASTM Standards, ASTM, Philadelphia, PA.
6. Dieter GE. Mechanical Metallurgy. Mc Graw Hill, London. 1976.
7. Kosec L, Kosel F, Vodopivec F. Proc. 4th E.C.F. Conf. Leoben. 1992; 653.
8. Eliasson L, Sandberg O, Berns H, et al. Proc. 2nd Int. Conf. Tooling, Bochum. 1989; 3- 14.
9. Dingremont N, Bergmann E, Collignon P, et al. Int. Conf. Metallurg. Coat. Thin Films, April. 1994.
10. Starling CMD, Branco JRT. Thermal fatigue of hot worktoolsteelwith hard coatings. 1997; 308-309: 436-442.
11. Davis JR. Powder metallurgy high-speed toolsteels, ToolMaterials, ASM Specialty Handbook. ASM International, Materials Park. 1995; 21-31.
12. Berns H, Lueg J, Trojahn W, et al. Powder Metal. Int. 1987; 19: 22.
13. Brandrup-Wognsen H, Engström J, Grinder O. Powder Metal. Int. 1988; 20: 18.
14. Meurling F, Melander A, Tidesten M. et al. Influence of carbide and inclusion contents on the fatigue properties of high speed steels and tool steels. Int. J. Fatigue. 2001; 23: 215-224.
15. Torres Y, Rodrıguez S, Mateo A, et al. Fatigue behavior of powder metallurgy high-speed steels: fatigue limit predictionusing a crack growth threshold-based approach. 2004; 387-389: 501-504.
16. German RM, Bose A. Injection Molding of Metals and Ceramics. MPIF, Princeton. NJ. 1997; 413.
17. Romano P, Lyckfeldt O, Candela N, et al. Mater. Sci. Forum. 2003; 369: 416-418.
18. Herranz G, Levenfeld B, Varez A, et al. Mater. Sci. Forum. 2003; 4361: 426-432.
19. Levenfeld B, Varez A, Torralba JM. Effect of residual carbon on the sintering process of M2 high speed steel parts obtained by a modified metal injection molding process. Metall. Mater. Trans. 2002; 33: 1843-1851.
20. Varez A, Portuondo J, Levenfeld B, et al. Mater. Chem. Phys. 2001; 67: 43.
21. Liu ZY, Loh NH, Khor KA, et al. Mater. Sci. Eng. A. 2000; 293: 46.
22. Jauregi S, Fernandez F, Palma RH, et al. Influence of Atmosphere onSintering of T15 and M2 Steel Powders. Metall. Trans. 1992; 23A: 389.
23. Varez A, Levenfeld B, Torralba JM, et al. Mater. Sci. Eng. 2004; A366: 318.
24. Dobrzanski LA, Matulaa G, Varez A, et al. Fabrication methods and heat treatment conditions effect on tribological properties of high speed steels. 2004; 157-158: 324-330.
25. Houzi Yuan. Study and application of compound castrolls of lowcarbon high chromiumcast iron. MetallSandong. 1999; 21: 63-66.
26. Changsheng Li, Jianzhong Xu, Xianghua Liu, et al. Study and application of oxidation film of hot steelrolling high chromiumcastironrolls. Steel. 2000; 35: 39-43.
27. Hwang KC, Sunghak L, Lee HC. Effects of alloyingelements on microstructure and fracture properties of cast high speed steel rolls: Part I. Microstructural analysis. Mater Sci Eng A. 1998; 254: 282-295.
28. Sano Y, Hattori T, Haga M. Characteristics of high-carbon high speed steel Rolls for hot strip Mill. ISIJ Int. 1992; 32: 1194-1201.
29. Hwang KC, Sunghak L, Lee HC. Effects of alloyingelements on microstructure and fracture properties of cast high speed steelrolls part I: microstructural analysis. Mater Sci Eng A. 1998; 254: 282-295.
30. Goto T, Matsuda Y, Sakamoto K, et al. Basic characteristics and microstructure of high-carbon high speed steelrolls for hot rollingmill. J. ISIJ Int. 1992; 32: 1184-1189.
31. XinzhaoYu, Shaokang Guan, Liguo Wang, et al. The effects of metamorphismtreatment on microstructure and properties of high speed steelused by compound rolls. T SteelIron Study. 2003; 15: 46-51.
32. Haifeng Liu, Yaohui Liu, SirongYu. The wear resistancestudy of high speed steel of high carbon and high vanadium. Tribology. 2000; 20: 401-406.
33. Long R, Wei S, Liu Y, et al. The microstructure and properties of high vanadium high wear alloys. Mine Mach. 2001; 12: 54-56.
34. Shizhong Wei, Rui Long. Study and application of peen of

high vanadium and high wear alloy. Cement. 2001; 8: 31-33.
35. Shizhong Wei, Rui Long, Feng Ni, et al. A new wear material – high vanadium high wear alloysthatapply to crash cementmaterial. Tribology. 2002; 22: 259-262.
36. Xiaotian Wang. Metalmaterials. Press House of Machine Industry. 1988; 131.
37. Zhen-Lin L, Yong-xin Z, Qi-Chang R, et al. An investigation of the abrasive wear behavior of ductile cast iron. Mater Process Technol. 2001; 116: 176-181.
38. Khruschov MM. The effect of wear on the compressive stress in the sphere on plane configuration. Wear. 1974; 28: 69-78.
39. Shizhong W, Jinhua Z, Liujie X, et al. Effects of carbon on microstructures and properties of high vanadium high-speed steel. 2006; 27: 58-63.
40. Holmberg K, Mathews A. Coatings Tribology, Property, Techniques and Application in Surface Engineering. Elsevier. 1994; 28: 1-442.
41. So H, Ya DS, Chuang CY. Formation and wear mechanisms of tribo-oxides and regime of oxidational wear of steel. Wear. 2002; 253: 1004-1015.
42. Straffelini G, Trabucco D, Molinari A. Oxidative wear of heat-treated steels. Wear. 2001; 250: 485-491.
43. Ueda M, Uchino K, Kobayashi A. Effects of carbon on wear property in pearlitic steel. Wear. 2002; 253: 107-113.
44. Goto H, Amamoto Y. Effects of varying load on wear resistance of carbon steel under unlubricated conditions. Wear. 2003; 254: 1256-1266.
45. Lin YC, Wang SW, Chen TM. A study on the wear behaviour of hardened medium carbon steel. J. Mater. Process. Technol. 2002; 120: 126-132.
46. Bahramia A, Mousavi Anijdana SH, Golozarb MA, et al. Effects of conventional heat treatment on wear resistance of AISI H13 tool steel. Wear. 2005; 258: 846-851.

© 2023 Jaouhar S, et al. This article is distributed under the terms of the Creative Commons Attribution 4.0 International License