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ANALYSIS OF FRICTION AND WEAR BEHAVIOR OF HEAT-TREATED HIGH CARBON HIGH CHROMIUM TOOL (D2) STEEL

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ABSTRACT

This experimental work intended to investigate the role of multiple tempering before and after cryogenic treatment on friction and wear behaviour of D2 tool steel as classified by American Iron and Steel Institute (AISI). D2 tool steel is used for measuring tools, blanking dies, forming dies, coining dies, long punches, forming rolls, edging rolls, master tools; extrusion dies, drawing dies, etc. The different combination of heat treatments like hardening (at 1020°C) for one hour, tempering (at 210°C) for two hours and deep cryogenic treatment (at -185°C) for 36 hours was done on D2 tool steel. Wear test were performed using pin-on-disc wear tester to which three different normal loads (6Kg,10Kg and 14Kg) and three different velocities (1m/s ,2m/s and 3m/s) were applied. Hardness of specimens was measured by using Rockwell Hardness tester. Microstructural characterizations of the differently heat treated specimens have been done by image analyzer software with inverted microscope. The findings show that the cryogenic treatment improves the wear resistance and hardness of D2 tool steel. The result indicates that, in HCT specimens there was large reduction in the wear rate and markedly enhancement in wear resistance of the D2 tool steel.

Keywords: American Iron and Steel Institute (D2) tool steel, cryogenic treatment, wear rate, wear resistance.

1. INTRODUCTION

Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and their resistance to deformation at elevated temperatures (red-hardness). Tool steels are used in cutting tools, punches, and other industrial tooling. Different tool steels are developed to resist wear at temperatures of forming and cutting applications.

Tool steel is generally used in a heat treated state. Conventional heat treatment gives hardness as well as toughness, wear resistance and ductility to steel. Even performed properly, conventional heat treating cannot remove all of the retained austenite (large, unstable particles of carbon carbide) from steel. The retained austenite as a soft phase in steels could reduce the product life and in working conditions, it can be transformed into martensite. This new martensite could cause several problems for working tools. This new martensite is very brittle and differs from the tempered one. Furthermore, this martensite causes micro cracks and reduces the product life. Regarding the problems mentioned above, the controlled transformation of retained austenite into martensite is essential to many types of component. In order to obtain this transformation the cold treatment is used.

2. LITERATURE REVIEW

Holzweissig et al. [1] It was done to characterise the microstructure of hot work tool steel that had undergone selective laser melting. The findings provided insight into how processing parameters and microstructural evolution interact. During layer-wise processing, it was discovered that martensite, which changes to austenite in a later tensile test, makes up a portion of the microstructure. This enhances the hot work tool steel's mechanical characteristics, permitting direct application**.**

Saboori et al . [2] At 1000–1200 °C and strain rates of 0.001–1 s1, the hot working behaviour of additively produced Ti–6Al–4V pre-forms by electron beam melting (EBM) has been investigated. A wrought Ti-6Al-4V alloy was also E3S Web of Conferences , 01 (2023) ICMPC 2023 430 210 https://doi.org/10.1051/e3sconf/202343001210 4 examined for comparison in the same way as the EBM alloy. The data assessments were done step-by-step to explore the hot working behaviour of these samples, and the stepwise process was detailed. Following the hot compression, no localised strain resulting from shear band development was discovered in the samples.

Hadi et al. [3] investigated the effect of cryogenic treatment on microstructural evolution and mechanical properties enhancement of AISI D2 tool steel. Cryogenic treatment down to liquid nitrogen temperature (77K) was added to the conventional heat treatment between hardening and tempering steps. Electron microscopy investigation showed higher volume fraction of fine carbides with average diameter below1 μm indicating effective retardation in carbide coarsening process as a results of cryogenic treatment. A modification in types of carbides was also observed after cryogenic treatment. X ray diffraction diagrams revealed transformation of retained austenite to martensite at cryogenic temperature.

Torkamani et al. [4] investigated the possibility of improving microstructure and mechanical properties of AISI D2 steel and decreasing the risk of cracking by bright hardening in comparison with oil quenching. The samples were fully prepared for performing the tests before the hardening processes because of high level of hardness that samples obtained after the treatment. Performing the heat treatment process began by preheating the samples at 650 ºC for 20 min prior to austenitizing. Then, they were austenitized at 1050 ºC for 45 min under the protective CO/CO2 atmosphere to avoid decarburization or oxidation of the alloying elements. The interrupted quench procedure was used for quenching.

Vahdat et al. [4] studied effects of microstructure parameters on tensile toughness of 1.2542 tool steel. During study, ten sets of 1.2542 tool steel specimens were DCT treated at -196 for 24, 36 and 48 hours and were tempered at 200 for 1, 2 and 3 hours. The results showed that the maximum population density of sub-micron sized secondary carbide was obtained after 36 h of soaking time. Also, amount of secondary carbides increased with soaking or tempering times from 2.18 vol% to 12.87 vol%. In addition, high population density and high content of secondary carbides were responsible for tensile toughness enhancement. Therefore, the best results (12-35% improvement in tensile toughness) were obtained for a specimen, which underwent a full treatment cycle consisting of heating, water quenching, soaking at -196ºC for 36 or 48 h and tempering at 200ºC for 1 or 2 h, respectively.

3. OBJECTIVES & METHODOLOGY

3.1 RESEARCH GAPS IDENTIFIED

From the literature review, it is found that cryogenic treatment has tremendous potential for enhancing the wear resistance, hardness and toughness of tool steel materials. Substantial work has been done on the effect of cryotreatment on different tool steels to enhance their mechanical properties. Cryotreatment technology has not been widely adopted by the industries due to lack of understanding of the fundamental metallurgical mechanisms and due to the wide variation in reported research findings.

So, Following are the gaps found from literature.

1. More useful work has been reported by several researchers, but there are many ambiguities in parameters like austenitizing temperature, quenching temperature, rate of cooling, soaking temperature, soaking period, rate of warming-up, tempering temperatures and tempering period needs further investigations and optimize all the parameters of DCT process for various materials.
2. For improving the properties of the steel austenitizing temperatures plays vital role so each material is to be assessed separately for selecting the optimum austenitizing temperature and should be co-relate to the desired properties after deep cryogenic treatment.
3. Literature of cryo treatment does not adequately clarify the selection of tempering temperature, tempering period and tempering cycle. So, there is a need to standardize the tempering process for particular tool steels.
4. One of the major uncertainties related to cryot reatment of tool steels is the duration of cryo treatment at the selected temperatures. So, there is a need to standardize the soaking time for cryo treatment for different tool steels.
5. The underlying mechanisms behind the enhancement of wear resistance of tool/die steels by deep cryogenic treatment are still debated and yet to get crystallized.
6. The greatest improvement in properties is obtained by selecting proper heat treatment process sequence, soaking time (cryo process time), stabilization, hardening temperature, heating and cooling rate.

Determination of appropriate level of the above parameters results in to enhance the product quality, productivity and wider acceptance in the industries. The main focus of this work is to standardizing processing cycles including austenitizing temperature, quenching temperature, soaking temperature, soaking period, tempering temperatures, tempering period and tempering cycles to optimize the properties of the material.

3.2 OBJECTIVES OF DISSERTATION

Following are the objectives of the project work,

1. To quantify the improvement in hardness and the wear resistance (WR) of the steel when it is cryogenically treated,
2. To understand the probable mechanism that is responsible for the improvement experienced, and
3. To confirm whether tempering has to be done before or after cryogenic treatment or it is immaterial.

3.3 METHODOLOGY

The optimum combination of heat treatment process is investigated to enhance wear performance of cryotreated cold work tool steel. For study AISI D2 cold working high carbon, high chromium content tool steel materials are selected. These cold work tool steel will be heat treated to achieve the different mechanical properties. The different combination of heat treatments like Pre heating at 720^0C for 30 min, hardening at 1020°C for one hour, quenching at 500°C for 20 minutes , tempering at 520°C for 90 minutes and deep cryogenic treatment at -185°C for 12 hours was done on tool steel.

The wear of any tool is a complex function of load and speed. Hence these two variables were considered for the study of wear behavior of tool steel. Wear test were performed using pin-on-disc Wear and Friction monitor. Testing conditions were used as follows,

a. Normal Load, F_N:- 6Kg, 10 Kg,14Kg
b. Sliding speed, V=1 m/s , 2 m/s, 3 m/s
c. Test Duration, T=60 Min.

The counter face surface used is EN 35 steel disc with roughness value of Ra < 0.5µm. Hardness of specimens was measured by using Vickers indentation method. Microstructural characterizations of the differently heat treated specimens have been done by image analyzer software with inverted optical microscope to study the controlled transformation of retained austenite to martensite and modification in precipitation behaviour of fine carbides.

4. EXPERIMENTAL METHODS

The present investigation has been conducted for studying effect of different heat treatment process sequence on wear behavior of cold work tool steel. Cold-work steels are restricted to applications at temperatures below 200-260^{0}C. They are divided into three groups: A (air-hardening steels), D (high-carbon, high-chromium steels) and O (oil-hardening steels). Group O and A steels are essentially high-carbon steels with a relatively low content of principal alloying elements so the hardenability of group O and A is less than group D steels.

Table No. 4.1 Chemical Composition of D2 Tool Steel

Sr. No.	Element	Weight Percentage	
		Content as per physical test conducted	AISI Specification of D2 Tool Steel
1	C	1.5	1.40-1.60
2	Mn	0.39	0.60 Max.
3	Cr	12.19	11.0-13.0
4	Mo	1.12	0.70-1.20
5	V	0.37	1.10 Max.
6	Iron	Remaining	

4.1 HEAT TREATMENT COMBINATIONS

The materials selected for this study were heat treated as per procedure prescribed in ASTM A 681-08 standards and the heat treatment process combinations to specimen are shown in Table 4. 1

Table No. 4.1 Different Heat Treatment Sequence.

Sr. No.	Heat Treatment Sequence	Heat Treatment Sequence Details
1	CHT (AQT)	Austenitizing + Quenching + tempering.
2	AQC	Austenitizing + Quenching + Cryogenic Treatment.
3	AQCT	Austenitizing + Quenching + Cryogenic + tempering.
4	AQCTT	Austenitizing + Quenching+ Cryogenic + double tempering.
5	AQTCT	Austenitizing + Quenching + tempering + Cryogenic + tempering.

4.2 MICRO-STRUCTURAL EXAMINATION

Microstructure analysis was carried by inverted optical microscope (Make-CARL ZEISS Germany, Model-AL350) at magnification 450X. Bakelite moulds are prepared and moulds are first surface leveled on endless emery belt (80/0) paper. Further samples were subjected to separately polishing on emery paper (240, 400, 600, 800 and 1000) so as to make surface free from scratches. Final polishing was done on velvet cloth polishing machine with intermittent application of fine suspensions of alumina to get better finish on polished surface. The polished specimens were etched using 3% Nital and 5% picral solution for microstructural examination. The freshly prepared etchant 'Nital', of composition approximately 3 ml Nitric acid with 100 ml ethyl alcohol and Picral of composition 5 g picric acid in 100 ml ethanol, was used for revealing micro constituents of tool steel. Microstructures were then recorded by image analyzer system. Different phases like retained austenite, untempered martensite, tempered martensite were checked.

4.3 HARDNESS MEASUREMENT

The hardness test was carried out by using Vickers Hardness test method. The samples were taken from each group and subjected to the hardness test. The Vickers hardness test carried out in such a way that three indentation were made in each test sample. The hardness number was determined based on the formation of the indentation due to the applied force. The flat surface was prepared by polishing paper on 1/0.

For Hardness measurement the load applied was 10 kgf for a dwell time 10s. Three readings are taken for each type of treatment and the arithmetic mean is used as Vickers hardness number. The average Vickers hardness number and its equivalent Rockwell hardness number are also calculating for discussion.

4.4 WEAR TEST

4.4.1 Experimental Test Rig

In order to investigate the wear resistance of the heat treated AISI D2 tool steels to adhesion wear, the pin on disc method was used. Dry sliding wear tests were carried out on computerized pin-on-disc "Wear and Friction monitor" (DUCOM: TR- 20LE-PHM-400) .The photograph of experimental set up is shown in fig. 4.1.1

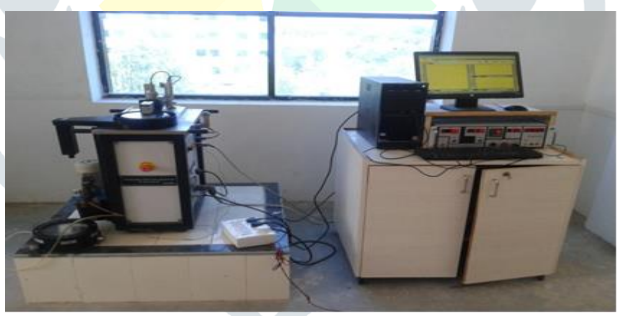


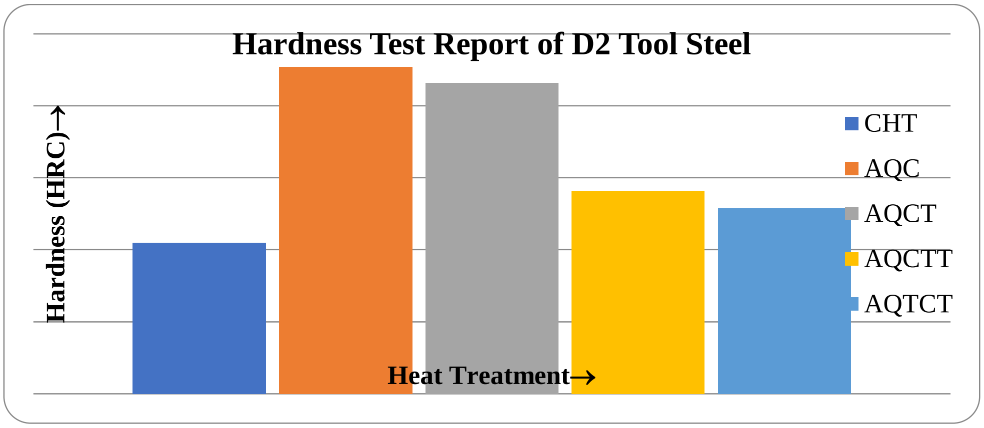
Fig. 4.1.1 Photograph of experimental set up (Tribometer TR-20LE). \

5. RESULT AND DISCUSSION

5.1 HARDNESS STUDY

Table No. 5.1 Percentage increase in hardness as compare to CHT Specimens

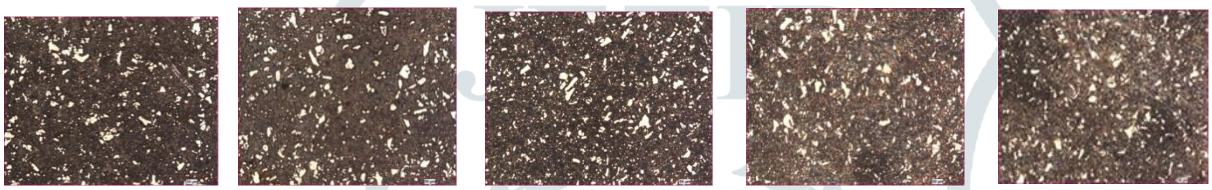
Sr. No.	Heat Treatment Sequence	D2		
		HV	HRC	% increase as compare to CHT
1	Conventional Heat Treated specimens (CHT)	805	64	0
2	Austenitizing Quenching Cryogenic (AQC)	927	68	15.15
3	Austenitizing Quenching Cryogenic tempering (AQCT)	916	67	13.79
4	Austenitizing Quenching Cryogenic tempering tempering (AQCTT)	841	65	4.47
5	Austenitizing Quenching tempering Cryogenic tempering (AQTCT)	828.7	65	2.94



Graph 5.1 Hardness test report of D2 tool steel for different heat treatment cycle

5.2 MICROSTRUCTURAL ANALYSIS

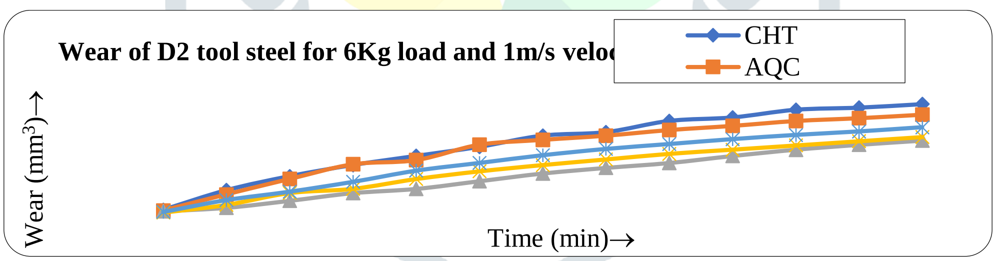
5.2.1 Microstructure analysis of D2 tool steel



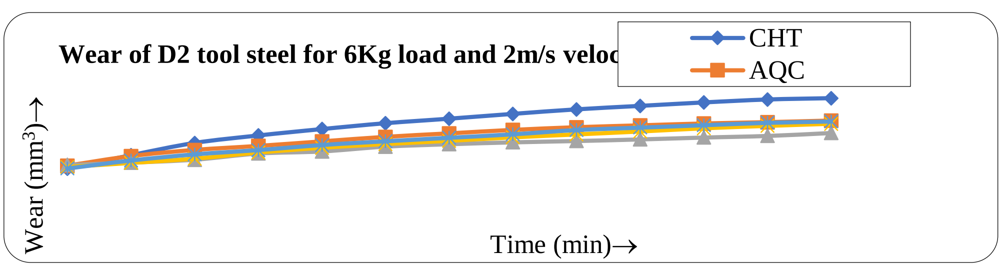
(a) (b) (c) (d) (e)

Fig. 5.2.1 Microstructure of various combinations of treatments for the specimen of D2 Tool steel a) CHT b) AQC c) QCT d) AQCTT e) AQTCT

5.3 WEAR MESUREMENT



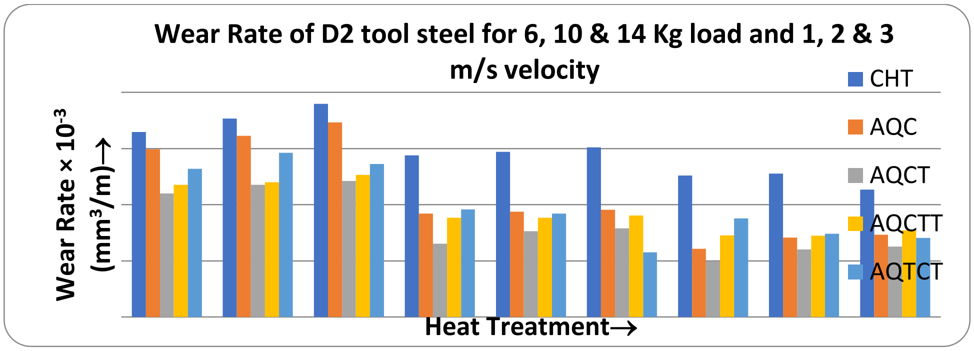
Graph No. 5.3.1 Wear of D2 material for 6Kg load and 1m/s velocity for different heat treatment.



Graph No. 5.3.2 Wear of D2 material for 6Kg load and 2m/s velocity for different heat treatment.

5.3.2 WEAR RATE (W_R)

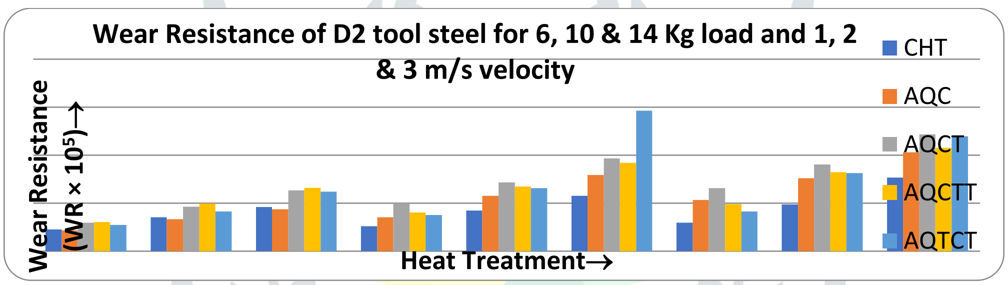
The estimated values of wear rate for all type of D2 steel specimens tested under normal loads 6Kg,10Kg and 14Kg and sliding velocity 1m/s,2m/s and 3 m/s are compiled in Graph No5.3.2



Graph No5.3.2.1 Wear Rate of AISI D2 for different heat treatment Process Sequence

5.3.3 WEAR RESISATANCE (WR)

Wear behavior can be conveniently expressed in terms of dimensionless wear coefficient (k). The inverse of dimensionless wear coefficient in known as wear resistance (WR).The calculated wear resistance of different heat treated specimens are depicted in graph .5.3.3.2



Graph No. 5.3.3.2 Wear Resistance (WR) of D2 tool steel for different heat treatment sequence

5.3.4 Improvement in wear resistance (α %)

Table 5.3.4.1 Improvement in Wear Resistance of D2 tool steel

Sr. No.	Specimen	Load (Kg)	Velocity (m/s)	WR ($\times10^5$)	% □ Compared to CHT specimen
1	CHT	6	1	2.2625075	0
2		6	2	2.5881715	0
3		6	3	2.9726653	0
4		10	1	3.5148007	0
5		10	2	4.2177609	0
6		10	3	4.8666472	0
7		14	1	4.581361	0
8		14	2	5.7556448	0
9		14	3	7.6649693	0
10	AQC	6	1	2.1655218	-4.2866

11		6	2	3.5109643	35.6542
12		6	3	5.3295176	79.28414612
13		10	1	3.3409514	-4.9462
14		10	2	5.7495442	36.3175
15		10	3	7.6070893	56.31067935
16		14	1	4.3537429	-4.968351108
17		14	2	7.9113728	37.45415283
18		14	3	10.280868	34.12797361
19	AQCT	6	1	2.9726653	31.38808601
20		6	2	5.0039865	93.34060745
21		6	3	6.5745808	121.1678792
22		10	1	4.6333208	31.8231
23		10	2	7.1485522	69.4869
24		10	3	9.0433491	85.82298507
25		14	1	6.3113343	37.76112164
26		14	2	9.6628705	67.8851082
27		14	3	12.148407	58.49257218
28	AQCTT	6	1	3.027911	33.82987681
29		6	2	4.0372146	55.9871
30		6	3	4.9052158	65.01069932
31		10	1	4.9547634	40.9685
32		10	2	6.7286911	59.5323
33		10	3	8.2164419	68.83167327
34		14	1	6.5778756	43.57907181
35		14	2	9.1931755	59.7245108
36		14	3	10.746952	40.20867637
37	AQTCT	6	1	2.7427116	21.2244
38		6	2	3.7712285	45.7101
39		6	3	4.1140674	38.39658975
40		10	1	4.1277127	17.438
41		10	2	6.545722	55.1942
42		10	3	8.1340222	67.13811102
43		14	1	6.1948713	35.21901679
44		14	2	14.610545	153.8472319
45		14	3	10.746952	40.20867637

6. CONCLUSION & FUTURE SCOPE

The present investigation based on the effect of cryotreatment on friction and wear behaviour of cold work tool steel. After conducting the experimental work, following conclusions can be drawn from the results

1. Cryogenic treatment is an add on process to conventional heat treatment process of tool steel.
2. Cryogenic treatment improves microstructure of metal i.e. controlled transformation of retained austenite into martensite.
3. The hardness of the cryotreated samples of AISI D2 tool steel showed an improvement of 2% to 15 % over the CHT samples. The increment in hardness may be attributed to the complete transformation of the austenite to martensite.
4. The hardness of AQC samples of D2 tool steel are highest but having less wear resistance because the untempered structure has the highest hardness but the material is more brittle due to presence of more untempered martensite which is seen in the microstructure. Hence, tempering should be done to reduce the brittleness by scarifying some hardness and to relieve internal stresses and to increase toughness and ductility.
5. The microstructure of D2 tool steel shows that upto maximum 80% the retained austenite was converted into martensite for same heat treatment process cycle.
6. The comparison of microstructure of AQC specimen and AQCT, AQTCT, AQCTT, CHT specimen of tool steel indicates that tempering subsequent to cryogenic treatment is essential to cause carbide precipitation in the martensitic matrix. These are also responsible for the improvement in the wear resistance.
7. The wear volume, wear rate (W_R) increases linearly with increasing normal load for all type of samples. Also it was observed that at higher velocities the wear rate is enhanced.
8. The lowest wear volume, and wear rate was observed in AQCT specimens of AISI D2 tool steel.

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