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Experimental Study on Mechanical and Tribological Properties of H13 Tool Steel Using Liquid Nitriding

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Abstract: In this paper the H13 tool steel specimen has been surface treated with the Liquid Nitridng process by varying processing time and with the constant temperature of 563°C. After the surface treatment, various tests like Rockwell Hardness, surface roughness, Pin on Disc tribometer are done with the H13 Tool specimens. Archard equation is used to calculate the specific wear rate and co-efficient friction for the H13 tool steels based on the wear volume loss and frictional force obtained from it. Likewise same H13 Tool Steel specimen are tempered with a temperature of 930°C and it is been quenched, same tests are taken for the Tool steel specimens. Finally the results are been compared with the Untreated, tempered Tool steel and Liquid Nitrided Tool steel of H13 specimen. It is found that the Liquid Nitrided Tool steel specimens are showing less wear rate and high hardness values when compared with the tempered Tool steels.

Key words: Liquid Nitriding · Archard equation · Specific wear rate · PVD coating · H13 Tool Steel · Tempering · Pin on disc Tribometer

INTRODUCTION

A coating is a covering that is applied to the surface of an object, usually referred to as the substrate. The purpose of applying the coating may be decorative, functional [1], or both. The coating itself may be an all-over coating, completely covering the substrate, or it may only cover parts of the substrate. An example of all of these types of coating is a product label on many drinks bottles- one side has an all-over functional coating (the adhesive) and the other side has one or more decorative coatings in an appropriate pattern (the printing) to form the words and images [2]. A major consideration for most coating processes is that the coating is to be applied at a controlled thickness and a number of different processes are in use to achieve this control, ranging from a simple brush for painting a wall, to some very expensive machinery applying coatings in the electronics industry [3]. A further consideration for 'non-all-over' coatings is that control is needed as to where the coating is to be applied. Many industrial coating processes involve the application of a thin film of functional material to a substrate, such as paper, fabric, film, foil, or sheet stock.

Liquid Nitriding: In Liquid nitriding (Salt bath nitriding) the nitrogen donating medium is a nitrogen containing salt such as cyanide salt. The salts used also donate carbon to the work piece surface making salt bath a nitrocarburizing process [4]. The temperature used is typical of all nitrocarburizing processes: 500°C - 570 °C. The advantage of liquid nitriding is that it achieves higher diffusion in the same period time compared to any other method. The advantages of salt nitriding are Quick processing time - usually in the order of 4 hours or so to achieve. Operation of this process is to heat the salt and work piece to temperature and submerge until the duration has transpired.

Physical Vapor Deposition: Physical Vapor Deposition (PVD) describes a variety of vacuum deposition methods which can be used to produce thin films. PVD uses physical process (such as heating or sputtering) to

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produce a vapor of material, which is then deposited on the object which requires coating. PVD is used in the manufacture of items which require thin films for mechanical, optical [5], chemical or electronic functions. Examples include semiconductor devices such as thin film solar panels, aluminized PET film for food packaging and balloons and coated cutting tools for metalworking. Besides PVD tools for fabrication, special smaller tools have been developed. Common industrial coatings applied by PVD are titanium nitride, zirconium nitride, chromium nitride, titanium aluminum nitride.

Tempering: Tempering**,** in metallurgy is the process of improving the characteristics of a metal, especially steel, by heating it to a high temperature, though below the melting point, then cooling it, usually in air. The process has the effect of toughening by lessening brittleness and reducing internal stresses. Suitable temperatures for tempering vary considerably, depending on the type of steel and designed application; for tool steels [6], the hardness of which must be retained, the range is usually from 200° to 250° C (400° to 500° F). The term is also used for hardening by cold-working, as in drawing wire or rolling sheet steel.

MATERIALS AND METHODS

Experimental Material: In this paper, High carbon high chromium steel is used and it is a H13 grade tool steel. As a result, Tools made with H13 type steel tend to brittle during hardening. It is dimensionally stable, has improved wear resistance and also has a higher cutting capacity. It had good edge holding properties [6], high compressive strength & high surface hardness after hardening. The chemical composition of the studied die metal AISI H13 was carried out using a scanning electron microscope and is listed in Table I.

Chemical composition of AISI H13 tool seel

Element	Content (%)
Chromium, Cr	4.75-5.50
Molybdenum, Mo	1.10-1.75
Silicon, Si	0.80-1.20
Vanadium, V	0.80-1.20
Carbon, C	0.32-0.45
Nickel, Ni	0.3
Copper, Cu	0.25
Manganese, Mn	0.20-0.50
Phosphorus, P	0.03
Sulfur, S	0.03

Fig. 1: Shows the H13 Tool specimen for 10 mm diameter & 30 mm thickness

For the Liquid Nitriding process of the H13 Tool steel material varying the processing time like 30,60,90,12,240 minutes and keeping at a constant temperature of 563°C.

Table 2: Shows the Varying process paramaters of the Liquid nitriding process

TEMPERATURE (°C)	PROCESSING TIME (MINS)
563	30
563	60
563	90
563	120
563	240

Experimental Tests

Mechanical & Tribological Property Tests: Hardness test, surface roughness and Pin on Disc Tribometer test were conducted on the untreated, liquid Nitrided and tempered specimen, to determine hardness, surface roughness, specific wear rate, co-efficient of friction, wear depth of the specimen respectively.

Rockwell Hardness Test: The hardness test has been done as per ASTM E18 standard on the digital Rockwell hardness testing machine. The specimens with dimensions of diameter 10 mm and length 30 mm are used for this test. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond indenter. This load represents the zero or reference position that breaks through the surface to reduce the effects of surface finish. After the preload, an additional load, call the major load, is applied to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load is then released and the final position is measured against the position derived from the preload, the indentation depth variance between the preload value and major load value. This distance is converted to a hardness number.

Table 3: Specification of the Digital Rockwell hardness Testing Machine

Material	H13 Tool Steel
Load applied on the material (Kgf)	150
Dwell Time	10 sec
Dimensions of the specimen	10mm x 30mm

Surface Roughness: The surface finish of a component may be critical for certain applications, affecting properties such as wear resistance, fatigue strength and coefficient of friction. Surface finish may also be critical for component assembly or system performance. Dimensional fit and mating surface interaction may require certain surface finish requirements to meet performance specifications.

Pin on Disc Tribometer: This Pin on Disc tribometer works on WinDucom software. Test plan and sample related information is entered in the machine control module before the start of a test. Software controls test parameters like speed, load, temperature and duration. Various outputs like friction force, wear depth are obtained. Co- efficient of friction and volume loss are estimated and displayed on the tribometer.

Table 4: Shows the specification of the Pin on Disc Tribometer test of the H13 Tool steel specimen

Speed	Min 100 rpm – Max 1000 rpm
Normal load	Max 100 N
Wear Track Diameter	Min 50 mm – Max 80 mm
Preset Timer	Max 99/59/59 (Hr/min/sec)
Specification size (Pin & Ball)	Dia (4,6,8,10,12)mm & ball (10) mm

RESULTS AND DISCUSSION

Hardness Test: The hardness test is done for the untreated, Liquid Nitrided, Tempered specimens of three samples each specimen and the test is carried out on the Digital Rockwell hardness tester. Where the dwell time is 10sec, in which the load applied on the material is 150Kgf as per ASTM standard G18.The hardness values of the liquid Nitrided material of H13 Tool steel with the processing time of 240 minutes and at a temperature of 563°C (55.8 HRC) shows more hardness value than the tempered H13 Tool steel material (54.9 HRC).

Table 5: Shows the Rockwell hardness values of H13 tool steel specimen.

Description	Untreated Tool steel (HRC)	Liquid Nitrided Tool steel (HRC)	Tempered Tool steel (HRC)
Sample 1	40.6	55.8	54.2
Sample 2	42.3	55.3	53.9
Sample 3	42.5	54.8	53.7

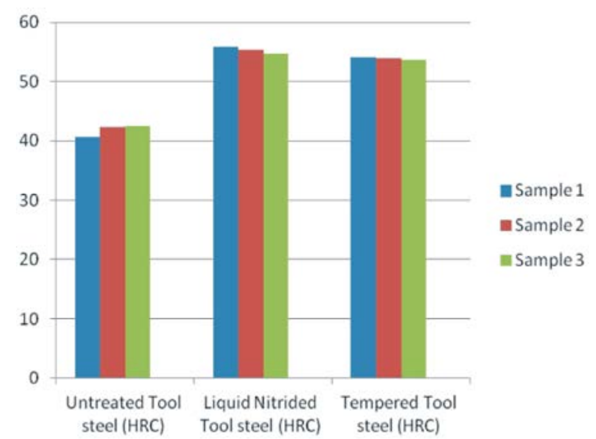

Fig. 3: Shows the hardness value comparison of the Liquid Nitrided, tempered & untreated H13 Tool steel.

Surface Roughness: The Surface roughness is done for the Untreated, Liquid Nitrided and tempered H13 Tool steel specimen of size 10mm diameter & 30 mm thickness.It is found that the Liquid Nitrided H13 Tool steel specimen has more surface roughness (Ra) value than the tempered H13 tool steel material.

Table 6: Shows the surface roughness results of the H13 Tool steel specimen

Untreated Tool steel (µm)	Liquid Nitrided Tool steel (µm)	Tempered Tool steel (µm)
0.9153	0.6582	0.5763
0.8359	0.6961	0.5897
0.9684	0.5638	0.5742

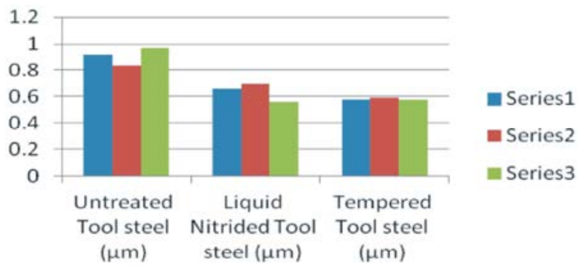

Fig. 4: Shows the comparison of the surface roughness values of H13 Tool steel specimen

Pin on Disc Tribometer Test

Pin on Disc Tribometer: Test has been carried out on the liquid nitrided materials with the varying loads of (15N, 30N, 45N) on the **WINDUCOM** Software to find out the wear depth & specific wear rate. Three samples were taken with the diameter of 10 mm and height 30 mm. The pin on disc tribometer was kept constant with a speed of 600 Rpm and with the sliding distance of 80 mm. The base material was a circular disk with the diameter of 100 mm.

Fig. 5: Shows the weight calculation for the wear volume on pin on disc tirbometer test

Table 7: Shows the Varying process paramaters and values of the Pin on disc tribometer test

Load (N)	Time (Min)	Speed (RPM)	Sliding distance (mm)	Wear depth (µm)	Frictional Force (N)
15	10	600	80	123	4.3
30	10	600	80	135	15
45	10	600	80	135	25

Archard Equation:

Specific wear rate = WV/ (F) * (SD)

where
WV = Wear Volume
F = Load Applied on the material
SD = Sliding Distance of the test material

Wear volume = (Wt of the material before testing – Wt of the material after testing)/ Density of the material.

Sliding Distance Calculation:

SD = πDN/ 60,000 (m/sec)

where
D = Diameter of wear track in mm
N = Disc speed in rpm

SD = (3.142) * (80) * (600) / 60, 000
= 150816 / 60,000
= 2.5136 (m/sec)

Calculation of Specific Wear Rate:

Wear Volume = (17.49-17.483) / 0.0078
= 0.007/0.0078
= 0.8974 m^2/N
0.8974 = K * (F) * (SD)
0.8974 = K * (15) * (2.5136)
K = 0.8974/ 37.704
K = 0.0238 m^2/N

Table 8: Shows the specific wear rate values based on the load applied on the material of the Pin on disc tribometer test.

Load applied on the material	Untreated Tool Steel (m^2/N)	Liquid Nitrided Tool steel (m^2/N)	Tempered Tool steel (m^2/N)
15 N	0.0238	0.0012	0.0016
30 N	0.0323	0.0018	0.0021
45 N	0.0386	0.0022	0.0024

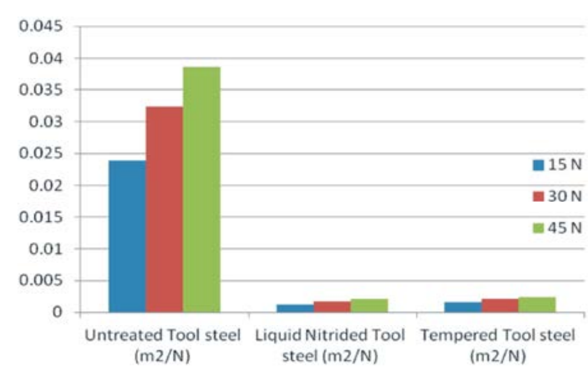

Fig. 6: Shows the comparison of the specific wear rate values of the H13 Tool steel specimen on pin on disc tribometer

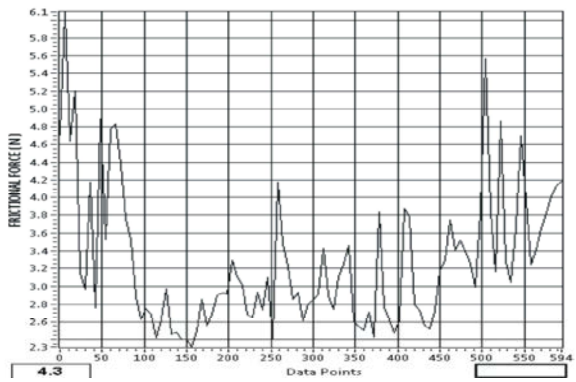

Fig. 7: Shows the wear depth of the H13 Tool steel on 15N load applied on to the material on Pin on disc test.

Calculation of Co-efficient of Friction:

Co-efficient of friction = frictional force (N)/ Load applied on the material (N)

Co-efficient of friction (μ) = 4.3 / 15
Co-efficient of friction (μ) = 0.28

Table 9: Shows the co-efficient of firction values based on the load applied on the material of the Pin on disc tribometer test

Load Applied on the material (N)	Untreated H13 Tool Steel	Liquid Nitrided H13 Tool Steel	Tempered H13 Tool Steel
15 N	0.28	0.21	0.24
30 N	0.5	0.19	0.20
45 N	0.62	0.17	0.18

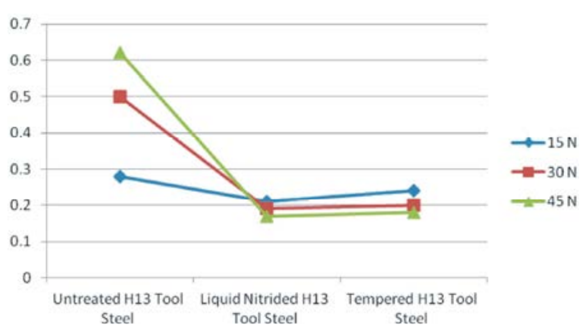

Fig. 8: Shows the co –efficient of friction for the H13 tool steel on pin on disc tribometer test

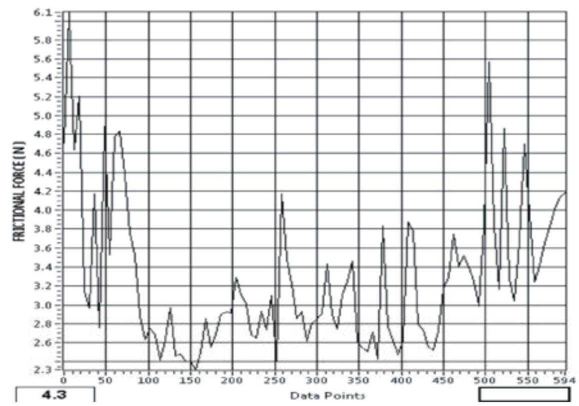

Fig. 9: Shows the frictional force values of the H13 Tool steel specimen on pin on disc tribometer test.

CONCLUSION

- In this experimental study it has been observed that Liquid Nitrided H13 tool steel material of 240 minutes & at a temperature of 563°C has increased hardness value than the Tempered Tool steel material of 10 mm diameter & 30 mm thickness.
- The surface roughness comparison shows that liquid nitrided material has high surface roughness (RA) value than the tempered material.
- The wear rate & co efficient of friction results shows that the liquid nitrided material posses less wear rate & co efficient of friction than the Tempered H13 Tool steel material.

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