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Study the Effect of Lubrication on Hardness in the Ring Compression Test

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ABSTRACT

This paper focuses on the hardness distribution in the mild steel ring specimens upset under rigid dies. Three different types of lubricants namely boric acid, Vaseline, grease and dry condition were employed as lubricants and the coefficient of friction corresponding to the lubricant employed was evaluated using standard 'Ring compression test'. The strain distributions obtained from the simulation studies were used to predict the hardness of the ring specimen. It can be reported from the experimental and predicted results that the hardness is not uniform at surface the deformed ring specimen and it varies at the bulge head on the surface and along the neutral plane.

Keywords: coefficient of friction, hardness, ring compression test, simulation

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INTRODUCTION

Friction is defined as the resistance to the relative sliding between two bodies in contact under a normal load. Metal working and manufacturing process are significantly affected by friction, because of the relative motion and the force present between tool and work pieces. An excess of friction produces heat, which causes expansion and breakdown of the tool. Friction has effects on the work pieces and process variables such as surface quality, roughness and internal structure of the product so that should be minimize friction between tool and work piece. Friction is reducing by using lubrication. Lubrication is process can take many different forms depending on the cutting parameter, geometry of the contacting bodies, the roughness, environmental conditions, and the physical and chemical properties of the lubricant. Friction factor can be used to study of the material flow, behaviour of material to achieve the desired product with minimum effort for example in processes of rolling, extrusion and forging.

As the measurement of hardness refers to the ability of the material to resist indentation, its importance in the metal-forming operation has led several researchers to correlate the values of stress or strain with the hardness. Ring compression test being the standard test for determining the magnitude of the friction prevailing at the die ring interface, it is necessary to analyze the hardness variation the deformed ring specimen. Ring compression tests were conducted on the mild steel to determine the value of the coefficient friction at the interface with different lubricating conditions. Three different types of lubricants namely boric acid, Vaseline, grease and dry condition were used as lubricants to minimize the environmental impacts. The hardness was measured along the radial axis, on the surface and from the billet center toward radial direction.

LITERATURE REVIEW

Menezes et al. (2010) [1] carried out experiments on the metal forming process to analyze the surface texture of the harder die surface and the effects of load on the varying friction conditions. The effort to minimize the non-uniform hardness distribution in the billet has not been reported in the bibliography. The objective of the present work is to optimize the process parameters responsible for the non-uniform distribution of the hardness in the billet, barrelling behaviour and deformation load using Taguchi technique. The optimum process parameters have been suggested and percentage of contribution of each parameter has also been noted down using ANNOVA analysis.

Muller et al. (2011) [2] performed multistage roll forming process on sheet metals to manufacture V-clamps. They developed a relation between plastic strain and micro hardness for the AISI 304 material. The V-clamp roll forming operation was also performed using finite element simulations. The strain near the bend portion of the V-clamp was predicted and the value of the micro hardness was evaluated using the relation developed. The microhardness values obtained from the experimentation was in close proximity with the values of the micro hardness obtained from the numerical equation.

Selvakumar et al. (2011) [3] studied on the powder metallurgy perform of different height (h) to the diameter (d) ratios. With the variation in the composition and aspect ratio, the change in load required for deformation was investigated. They related the stress and strain parameters with the relative density and analyzed the formability of the material. The micro forming process which undergoes high frequency vibration amplitude assists in improving the softening and hardening of the material.

Davidson et al. (2015) [4] studied on the hardness distribution in the AA2014-T6 billets upset under rigid dies. The solid cylinders of height 24 mm and diameter 24 mm were compressed to different levels of strains by employing soap, boric acid and Vaseline as lubricants on the faces of the billets and the friction factor (m) obtained from the ring compression test for the lubricants was given as input to the finite element software to examine strain distribution inside the cylinders. The strain distribution in the solid cylinders was correlated with the hardness distribution (VHN) and an equation was proposed to obtain the hardness of the billet.

Zhang et al. (2017) [5] studied that oscillating cold forging (OCF) compared with conventional cold forging (CCF) and hardness test and micro observation were performed which can be contributed to the factors including friction, elastic deformation of die and the metal flow according to the simulations and experiments [6-7]. The results of experiment and simulation indicate the surface quality of OCF is better than CCF because lower friction leads to less and the highest value of hardness 305.6HV5 occurs in CCF, which is larger than 275.1HV5 in OCF.

MATERIALS AND METHODS

Specimen Material and Dimensions

Mild steel is selected as the material. The specimens were machined to the sizes of outer diameter, inner diameter and height ratio of 6:3:2 (Male and Cockcroft, 1964). The mild steel rod of 45 mm diameter was machined to the required outer diameter of 42 mm, inner diameter 21 mm and height of 14 mm by using lathe machine (Figure 1).

Compression Testing Machine (CTM)

Compression testing machine is designed to test materials and other materials under compression, bending, transverse and shear loads. Ring compression test was conduct on mild steel using compression testing machine which show in Figure 2.

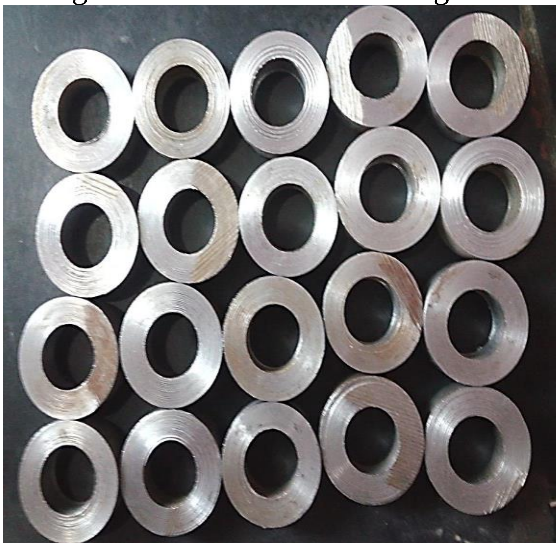

Fig. 1. *Specimens used in experiment.*

Fig. 2. *Compression testing machine.*

Rockwell Hardness Test

The hardness of mild steel ring after compression was test using the Rockwell hardness tester which is show in Figure 3. Rockwell hardness tester is an indentation test using verified machine to force use diamond conical or hard steel ball indenter under specified condition into the surface of the material. There is different scale to measure hardness are HRC, HRB and HRA. For present work hardness value were obtain on Rockwell hardness tester C scale (HRC).

Fig. 3. *Rockwell hardness test.*

Experimental Procedure

The experimental procedure was devised by the authors and strictly followed over the range of all experiments. The non-related parameters such as the compression speed, the die surface roughness, and the environment temperature and humidity, were all kept at constant values. The process of experiment be carried out by changing the different lubrication Boric acid, Grease, Vaseline) and load (1000–1400) kN to determination of coefficient of friction. The initial dimensions of the ring in the following ratio, outer diameter: inner diameter: height = 6:3:2 were adopted as standard dimensions in ring test method. Dimensions were taken as outer diameter 42 mm inner diameter 21 mm and height 14 mm. Apply lubrication at upper and bottom surface of work piece and compress apply different load condition. After each stage of the deformation process, dimensions were measured using digital Vernier calliper. In the given Figures 4 and 5, the ring specimens are show after the compression process.

The dimensions of specimen were measure after deformation and substituting in the following equations given as below:

$$m = \frac{-1}{2\frac{\mathrm{Ro}}{\mathrm{H}}\left(1+\frac{\mathrm{Ri}}{\mathrm{Ro}}-2\frac{\mathrm{Rn}}{\mathrm{Ro}}\right)} \times \ln\left[\left(\frac{\mathrm{Ri}}{\mathrm{Ro}}\right)^2 \times \frac{\left(\frac{\mathrm{Ro}}{\mathrm{Ro}}\right)^2+\sqrt{3+\left(\frac{\mathrm{Rn}}{\mathrm{Ro}}\right)^4}}{\left(\frac{\mathrm{Rn}}{\mathrm{Ro}}\right)^2+\sqrt{3\left(\frac{\mathrm{Ri}}{\mathrm{Ro}}\right)^4+\left(\frac{\mathrm{Rn}}{\mathrm{Ro}}\right)^2}}\right] \quad (1)$$

$$\mathrm{Rn} = \mathrm{Ro}\sqrt{\frac{\left(\frac{\mathrm{Ri}}{\mathrm{Ro}}+\frac{\Delta\mathrm{Ri}}{\Delta\mathrm{Ro}}\right)}{\left(\frac{\mathrm{Ro}}{\mathrm{Ri}}+\frac{\Delta\mathrm{Ri}}{\Delta\mathrm{Ro}}\right)}} \quad (2)$$

$$\mu = \frac{\mathrm{m}}{\sqrt{3}} \quad (3)$$

where R_i is the inner radius of specimen after deformation, R_o the external radius of the specimen after deformation, ΔR_o the change in outer radius of the specimen after deformation, ΔR_i the change in internal radius of the specimen after deformation, R_n the mean radius of the specimen after deformation, h the height of the specimen after deformation, m the friction factor, and μ is the coefficient of friction.

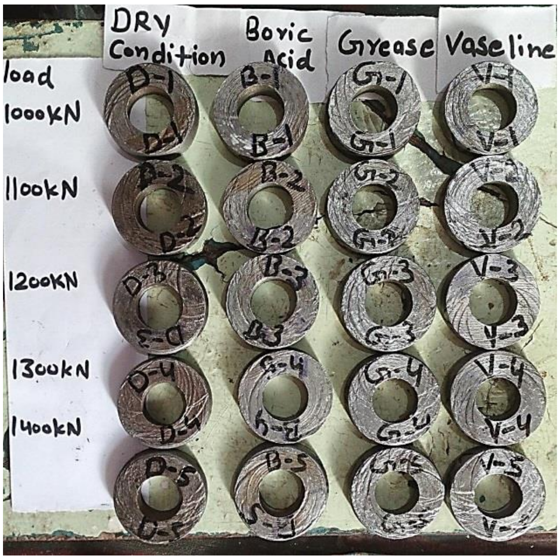

Fig. 4. *Specimens after compression.*

(a) Dry condition

(b) Boric acid

(c) Vaseline

(d) Grease

Fig. 5. *After deformations at different load.*

Hardness Measurement

Hardness measurement by using Rockwell hardness tester, which employs indenter as conical diamond 120° and select load as 150 kfg and used hardness scale C to measure hardness value as HRC. Hardness values were measured on the surface on deformed work piece at a regular interval of 2 mm along the radial direction from the inner edge to outer edge of the specimen.

A schematic representation of the locations of hardness measurement after the compression is shown in Figure 6. Hardness measurements were performed on radial three lines each was 120° apart each other. Four reading taken on each line and experiments were conducted for each condition and the average hardness was considered for analyses. The same experimental procedure was followed for all the load and lubricating conditions mentioned earlier.

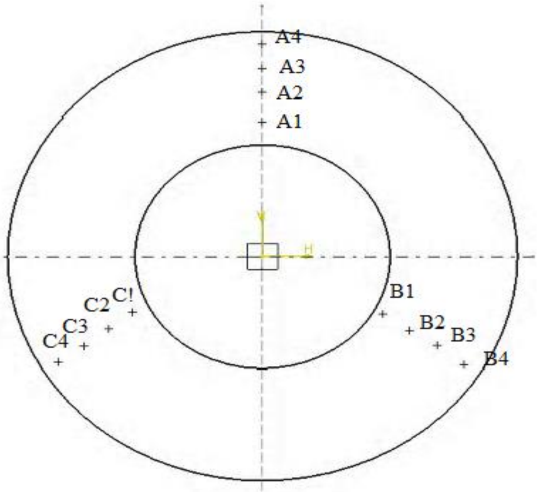

Fig. 6. *Hardness distribution radial directions of work piece.*

where A_1 point 2 mm from inner edge of work piece, A_2 point 4mm from inner edge of work piece, A_3 point 6mm from inner edge of work piece, A_4 point 8mm from inner edge of work piece.

RESULT AND DISCUSSIONS

Experimental Determination of Coefficient of Friction

Ring-compression tests were performed on Mild steel. The tests were conducted using the ring geometry ratio of 6:3:2 (Male and Cockcroft, 1964) with the actual physical dimensions of the ring being 42 mm outer diameter, 21 mm inner diameter and 14 mm height (thickness). The tests were performed under room temperature of 25°C using three lubricants as Boric acid, Vaseline and Grease to study the coefficient of friction and the performance of the lubricants. The dimensions of specimen after compression were measured using digital Vanier calliper. However, due to barrelling and irregularity on both inner and outer cylindrical surfaces of specimen, five readings were taken, and an average value was recorded and Avitzur (1986) [7] equations were used to determine the coefficient of friction (Figure 7).

Table 1. *Experimental table for ring compression test.*

Lubrication condition	Load (kN)	Outer radius (R_o) (mm)	Inner radius (R_i) (mm)	Height h (mm)	R_n (mm)	ΔID (%)	ΔH (%)	m	μ	Average μ
Dry condition	1000	22.18	10.14	12.18	12.20	3.42	13	.64	.37	0.38
	1100	22.34	9.98	11.82	12.59	4.95	15.57	.72	.42	
	1200	22.67	9.91	11.25	12.30	5.56	19.42	.63	.36	
	1300	22.72	9.75	10.98	12.48	7.14	21.57	.61	.35	
	1400	22.91	9.39	10.25	13.05	10.7	26.78	.72	.42	
Boric acid	1000	22.40	10.79	12.11	12.28	-2.76	13.5	.45	.26	0.27
	1100	22.49	10.86	11.56	12.56	-3.42	17.42	.48	.27	
	1200	22.77	10.99	11.31	12.94	-4.66	19.58	.51	.29	
	1300	23.37	11.04	10.41	13.06	-5.14	25.64	.46	.26	
	1400	23.60	11.12	9.85	13.79	-5.57	29.64	.50	.29	
Vaseline	1000	22.44	10.86	12.05	11.28	-3.42	13.92	.35	.20	.0.22
	1100	22.58	10.91	11.42	12.38	-3.90	18.42	.38	.21	
	1200	23.91	11.08	11.25	12.67	-5.52	19.64	.41	.23	
	1300	24.15	11.24	10.32	12.98	-7.04	26.28	.41	.23	
	1400	24.40	11.28	9.80	13.12	-7.42	30.00	.42	.24	
Grease	1000	22.84	10.92	12.00	1.89	0.42	12.54	.19	.10	.092
	1100	23.14	11.04	11.24	2.13	0.54	12.90	.16	.09	
	1200	23.92	11.14	11.15	2.92	0.64	13.46	.18	.10	
	1300	24.37	11.51	10.02	3.37	1.09	13.70	.15	.08	
	1400	24.49	11.62	9.65	3.49	1.12	13.28	.17	.09	

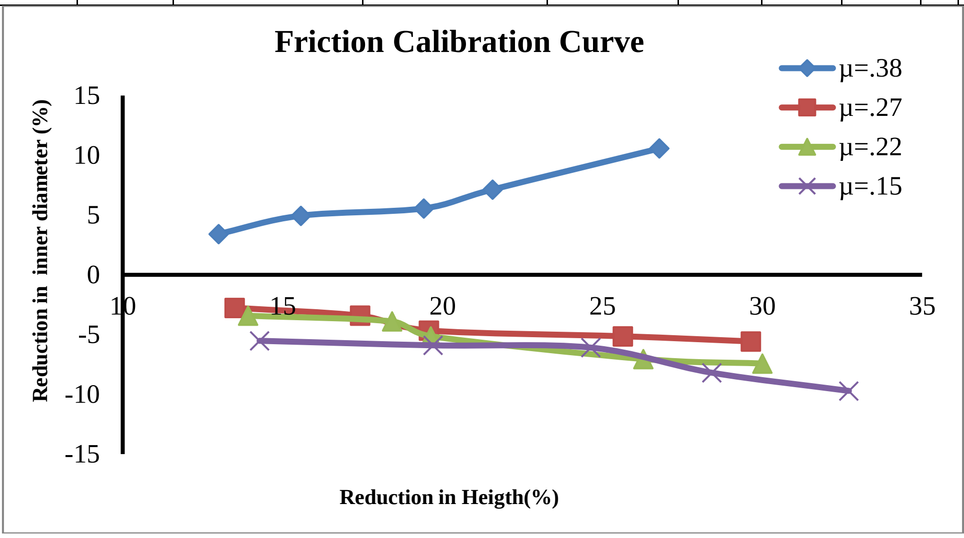

Fig. 7. *Combine friction calibration curve.*

Hardness Distribution

The hardness of material was measure from the inner edge to outer edge in radial direction at specific load and lubrications conditions as boric acid, Vaseline, Grease and dry condition. Here, the coefficient of friction values for the lubricants were obtained through ring compression tests.

Table 2. *Average hardness distributions (HRC) in radial direction at load 1000 kN.*

Distance from inner outer edge (mm)	Average hardness (HRC) at different lubrications			
	Dry condition	Boric acid	Vaseline	Grease
2	9.16	11.5	12.83	17.33
4	9.83	12	13.6	18
6	12	13.3	15.1	18.5
8	13.5	14.5	16.16	19.67

The hardness distribution in radial direction is shown in Figure 8. It can be observed that hardness is increasing radically outward. The hardness level at radius of specimen is increasing with respect to lubrication. The minimum hardness was observed at dry condition while the hardness increased with boric acid, Vaseline and grease. The increase in hardness may be due to strain hardening of the specimen as the deformation increased with better lubrication.

Table 3. *Average hardness (HRC) distributions in radial direction at load 1100 kN.*

Distance from inner to outer edge (mm)	Average hardness(HRC) at different lubrications			
	Dry condition	Boric acid	Vaseline	Grease
2	13.83	15.67	16.67	24.3
4	14.5	17.67	18.33	25.17
6	16.33	19.0	22.33	25.67
8	18.63	19.67	22.67	25.83

From the Figure 8 shows that results lubricants Grease a relatively smaller change in hardness throughout the radial distance. The hardness varies for lubricant as Grease within a span of 24.3 HRC at the inner edge to 25.83HRC at outer end.

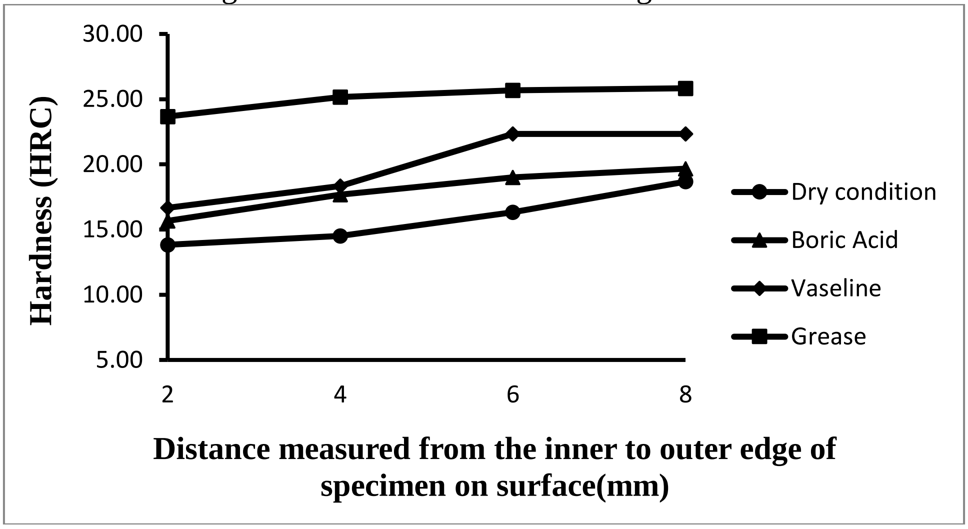

Fig. 8. *Hardness distribution of different lubrication at load 1100 kN.*

Table 4. *Average hardness (HRC) distributions in radial direction at load 1200 kN.*

Distance from inner to outer edge (mm)	Average hardness (HRC) at different lubrications			
	Dry condition	Boric acid	Vaseline	Grease
2	16.33	20.18	23.18	25
4	16.83	22.67	24.17	25.83
6	17.17	23.5	25.67	26.50
8	19.67	24.83	26	27.83

From the Figure 9 the hardness varies for lubricant as Grease within a span of 25 HRC at the inner edge to 27.83HRC at outer end.

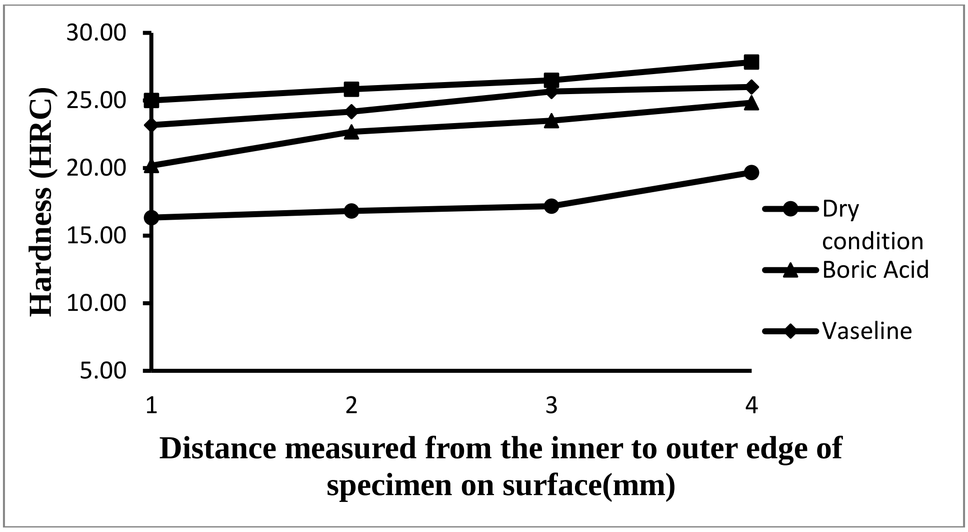

Fig. 9. *Hardness distribution of different lubrication at load 1200 kN.*

Table 5. *Average hardness (HRC) distributions in radial direction at load 1300 kN.*

Distance from inner to outer edge (mm)	Average hardness(HRC) at different lubrications			
	Dry condition	Boric acid	Vaseline	Grease
2	19.83	23.01	24.33	26.33
4	20.83	23.67	24.83	26.83
6	21.50	24.67	26.17	26.83
8	24.50	26.5	26.83	28

From the Figure 10 the hardness varies for lubricant as Grease within a span of 26.33 HRC at the inner edge to 28 HRC at outer end.

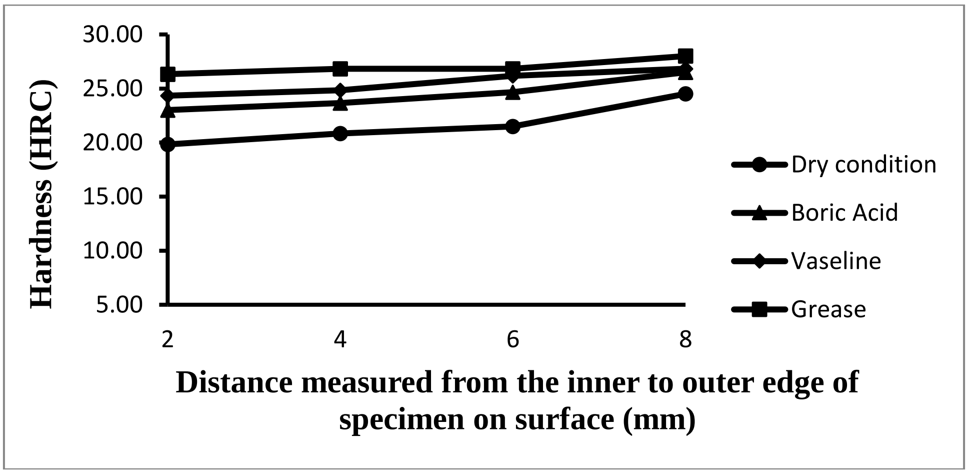

Fig. 10. *Hardness distribution of different lubrication at load 1300 kN.*

Table 6. *Average hardness (HRC) distributions in radial direction at load 1400 kN.*

Distance from inner to outer edge (mm)	Average hardness(HRC) at different lubrications			
	Dry condition	Boric acid	Vaseline	Grease
2	22.83	26.17	26.33	28.17
4	23.67	26.50	26.83	28.87
6	23.83	27.50	27.17	29.83
8	25.50	28.17	28.83	29.83

From the Figure 11 the hardness varies for lubricant as Grease within a span of 28.17 HRC at the inner edge to 29.83 HRC at outer end.

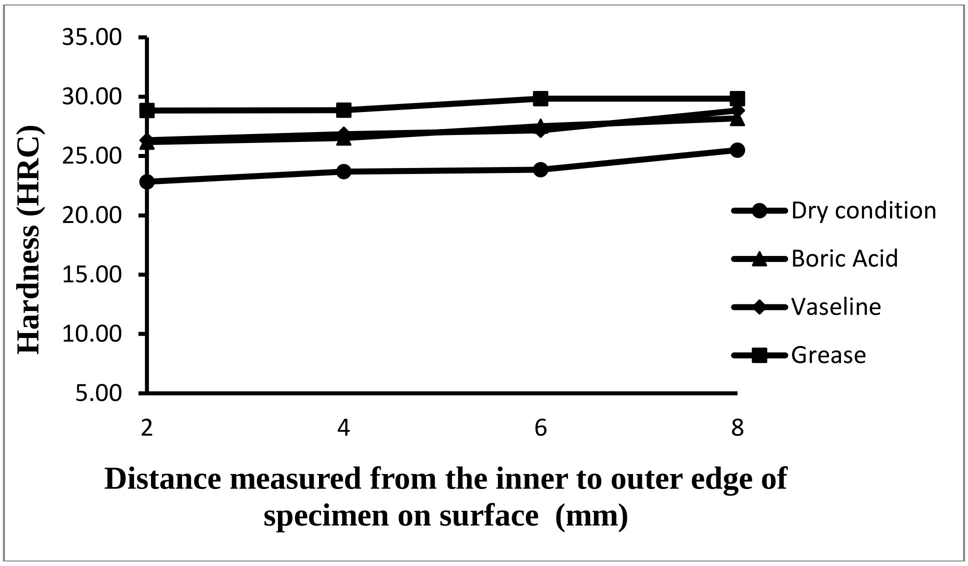

Fig. 11. *Hardness distribution of different lubrication at load 1400 kN.*

Figures 8 to 11 show that hardness distribution increases centre to outer this is because of the mobility of particles from inner to outer edge as metal flows outward without any restriction that the bulging at the outer diameter of the ring specimens resulting at outer surface hardness more than inner. So, the hardening ability should increase from the billet geometric centre to its periphery.

Figure 12 shows that the load increases the hardness also increase. For steels, increasing compression load is an increase of the yield and tensile strength which generally leads to an increase in hardness material. Since the hardness increases with the increase in strength and increase in strength led to increase in brittleness.

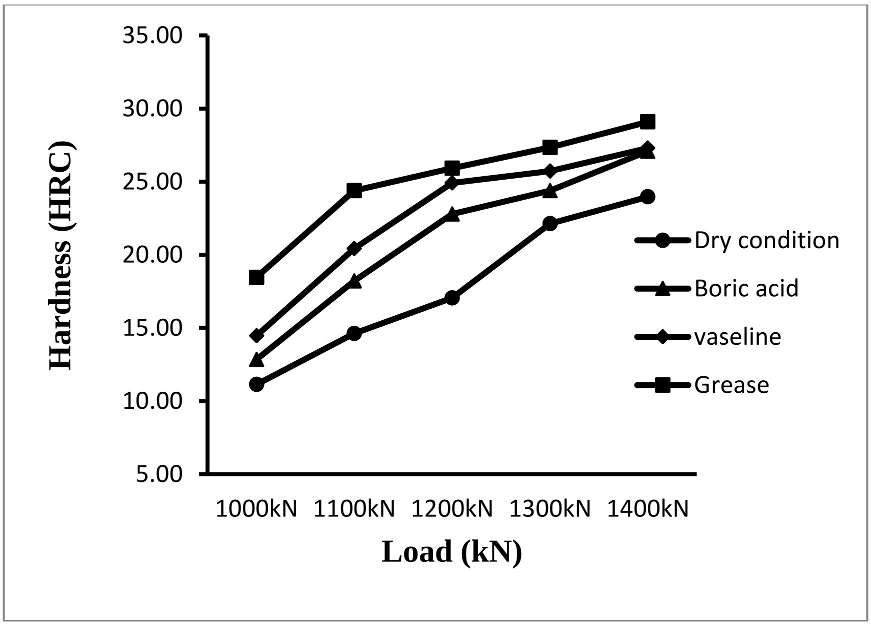

Fig. 12. *Hardness distribution of different lubrication.*

The hardness also increases with decrease in coefficient of friction. The lowest coefficient of friction Grease (μ=.16) was hardness maximum and for dry condition (μ=.38) hardness is minimum. Because of the relatively high friction condition (μ=.38), the material tends to bulge toward the inner of the hole and near the outer periphery. The material near the bulged portion make less strict in case of (μ=.38), as compared to (μ=.26), (μ=.22), and (μ=.16). This behaviour is responsible for the hardness variation for different friction condition.

CONCLUSIONS

The hardness is always minimum near the inner side in the deformed ring irrespective of any magnitude of coefficient of friction. The decrease in the magnitude of the coefficient of friction increases differential strain hardening in the billet and the peak value of hardness inside i.e. grease lubrication hardness more than dry conditions. The bugling effect of the hole in upset ring specimen plays a significant role in the hardness variation. The hardness near the inner diameter of the hole is less than outer bugling surface because of the differential strain hardening occurs at the hole and bulging of the outer diameter.

The hardness is more in case Grease (μ=.16) of when compared to and as boric acid (μ=.26), Vaseline (μ=.22), (μ=.38). This is because when grease was employed on the surface as lubricant, the material on the surface tends to flow freely which is not the case with the boric acid, Vaseline and dry condition. This is also responsible for the minimum hardness at inner on the surface compared to the outer portion of the ring specimen. A relative difference in the hardness values for Grease (μ=.16), boric acid (μ=.26), Vaseline (μ=.22), and dry condition (μ=.38) can be observed in Figure 12 of the difference in the strain distribution.

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