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Numerical and Experimental Analysis of Wear Behaviour of Diamond like Carbon Coated ZA-27 Alloy

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Abstract:

The objective of the work is to investigate the wear of diamond like carbon coatings (DLC) by experimental and finite element method. The DLC coatings were deposited onto the ZA-27 alloy substrate using plasma assisted chemical vapour deposition technique. The pin-on-disc tests were conducted under different operating conditions. A three dimensional Finite element analysis (FEA) is used to simulate the pin on disc experiments through a developed model of the wear characteristics of the coating materials. The FEA result was validated with uncoated samples using analytical solutions for Hertzian constant with frictional effect. The influence of coating and ZA-27 alloy on the deformation, strain of the coating was studied. The FEA results shows that the lowest wear and deformation were observed in DLC coating specimens. Also both wear and deformation increase with increasing normal load and sliding velocity.

Keywords: Diamond like carbon coating, ZA-27 alloy, FEA, Wear, deformation

1. Introduction

Diamond coated carbon (DLC) coated components have high specific strength, excellent wear resistance and lower coefficient of friction, which boost many applications in automotive[1], aerospace[2] and other applications[3]. On other hand non-ferrous alloys like Zinc- Aluminum 27 (ZA-27) find bearing applications at room temperature due to its lower density and lower frictional values [4]. But, they lose mechanical strength at higher speed and higher normal loading conditions [5-7]. The DLC coatings are more potential protective layers or wear components during rubbing against the hard materials[8]. This makes them most suitable for various tribological applications[9].

Recent industrial trend shows DLC coating deposited using different techniques of both physical and chemical deposition technique such as physical vapor deposition[10], magnetron sputtering[11], cathodic arc discharge[12], plasma assisted chemical vapour deposition[13], etc. The DLC coatings are used for ferrous materials or super alloys [14-16] but no or few works are available on non-ferrous materials especially aluminium and zinc alloys. Although many researchers investigated DLC coated for tribological behavior, they showed excellent in wear resistance and low friction coefficient, but poor connections to the substrate due to the residual stresses developed between the host materials that add DLC coatings. The present work focuses numerical investigation of wear and deformation using DLC coating and ZA-27 (host material) Young's modulus, coefficient of thermal expansion, which are the most significant factors for residual stresses between the coatings.

2. Experimental studies

In Present work, 8 mm dia x 20 mm length ZA-27 alloys (composition of Al-25%, Cu-2%,Mg-0.01, Zn-balance) was selected as a host material for coating. Both the circular faces of the specimen were polished with standard procedure, then DLC coating was carried out in aa hybrid system of CVD and PVD technique. The process used 40 W power, 125 mTor, duration of coating 270 min, gas flow rate of 75 cm^3/s and CH_4:Ar ratio is 83.17. The wear test of coated samples was conducted under normal load of 10, 20 and 30N and with a disc rotating speed of 100, 200 and 300rpm with the sliding distance kept constant at 1000m.

3 Finite Element Analyses

Wear simulation was carried out using Ansys workbench Archard wear method is used for wear analysis for both coated and uncoated specimen. The pin and disc modeling is done in Ansys design modeler and shown in Fig. 1 and the dimensions of pin 10 mm dia x 30 mm and disc (100 mm dia x 5 mm thick). Pin with Dimple textures of 200 µm and 1mm spacing are modeled on pin surface and then imported in Ansys design modeler for analysis, which is shown in Fig. 2.

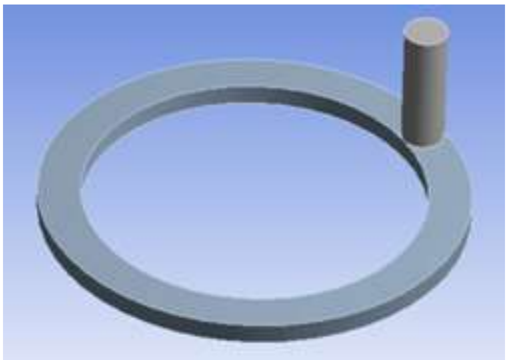

Fig 1 Model of pin and disc

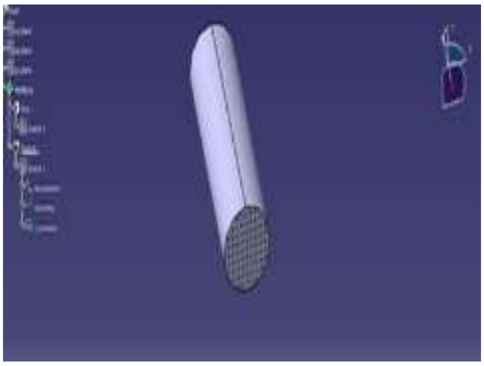

Fig 2 Pin with coating.

Archard Wear model

Archard wear model is used for simulating wear. This law assumes that the volume loss due to wear is linearly proportional to the contact pressure and the sliding velocity at the contact surface.

The rate of wear at contact node is given by

$$W=\frac{K}{H}p^{m}v^{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

K=wear co-efficient

H=material Hardness

p=contact pressure

v=Relative sliding velocity

m=pressure exponent

v=velocity exponent

Properties of pin and disc Material

The Pin material is Nickel aluminum bronze, whereas disc material is Tungsten. The properties of pin and disc material is shown in Table 1

Table 1 Properties of Pin and Disc material.

Property	Pin	Disc
Density	5190 kg/m^3	19300 kg/m^3
Young's Modulus	$1.5x10^{11}$ Pa	$4x10^{11}$ Pa
Poisson's ratio	0.32	0.28
Bulk Modulus	$1.3889x10^{11}$ Pa	$3.0303x10^{11}$ Pa
Shear modulus	681810^{10} Pa	$1.5625x10^{11}$ Pa
Tensile Yield strength	$4.7x10^{8}$ Pa	$7.5x10^{8}$ Pa
Compressive Yield strength	$1.035x10^{9}$ Pa	$1.35x10^{9}$ Pa
Tensile Ultimate Strength	$7.6x10^{8}$ Pa	$9.8x10^{8}$ Pa
Hardness	640N/mm^2	995N/mm^2

Modeling of Pin on Disc

The contact between pin and disc material is frictional and the friction co-efficient of 0.27 is entered with behavior as symmetric. Augmented Lagrange contact formulation method is used. Nodal normal to target detection method and Update stiffness to each iteration is used. The APDL commands used for simulating wear where K, H, m and n are the input parameters. TB, WEAR,cid,,,ARCD command is used to activate archard wear model.TBFIELD command is used to define time and TBDATA command is used to specify input values K,H,m,n.

Elements used for wear calculations are Contac 174 which are 3D 8node surface to surface contact elements and Target 170 which represent the 3D target surface .The pin and disc are meshed using face sizing with element size 2mm.

The behavior for pin is given as rigid and the surface elements of the pin are considered as contact elements, the Disc behavior is given as flexible (rotating), and elements at the bottom of the disc is considered as target elements. For simulation purpose loads of 10N, 20N & 30 N is applied on the top face of the pin as shown in Fig 6.

The displacement in the X and Y direction of the outer round faces of the pin are restricted, so given the value as zero. At the same time, Z direction displacement is given as free, for allowing the movement of pin only in the Z direction which is shown. Fixed Support is given to pin as shown in Fig. 7. Joint Condition applied between pin and disc is rotary and Rotational velocity for the disc is varied between 100, 200rpm the disc is rotated in z direction which is shown in Fig. 8. For simulation Number of steps is given as 10 and time is given as 1 sec and the analysis is carried for 10sec. Initial time step is 0.1 sec, Minimum time step is given as 0.01 sec and maximum time step is 1 sec. smaller the time step better the accuracy of results.

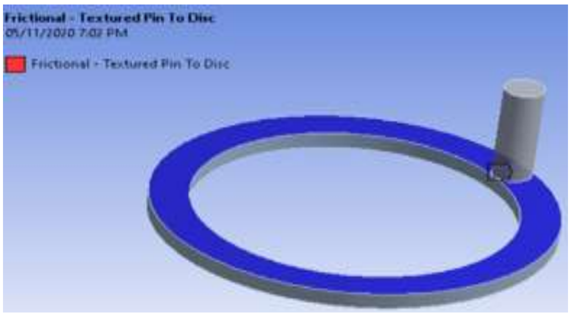

Fig 3 Contact type Frictional disc to Pin.

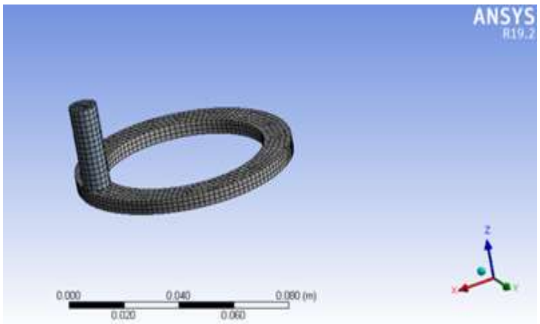

Fig 4 Meshing of Pin and Disc

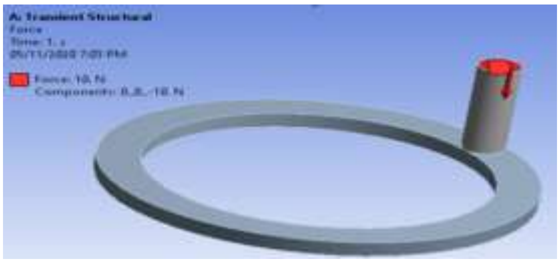

Fig 5 Force application on pin

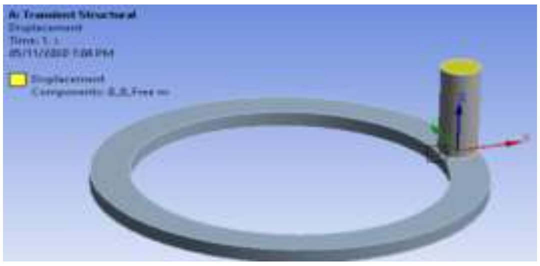

Fig 6 Displacement of Pin.

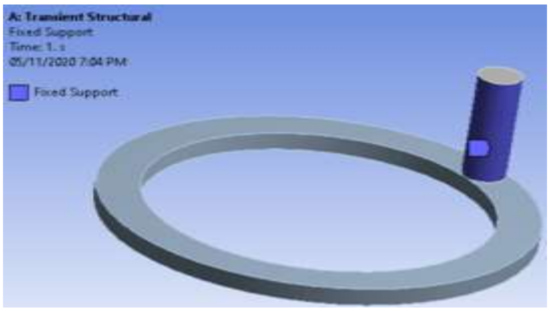

Fig 7 Fixed Support for Pin

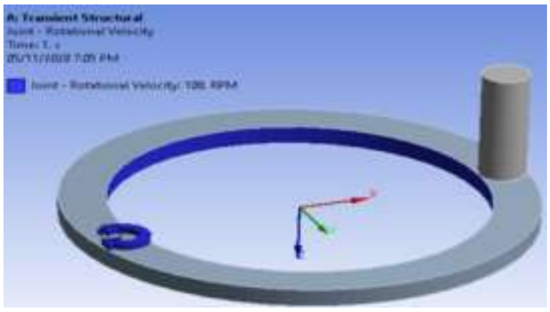

Fig 8 Rotational Velocity of Disc.

4. Result and Discussion

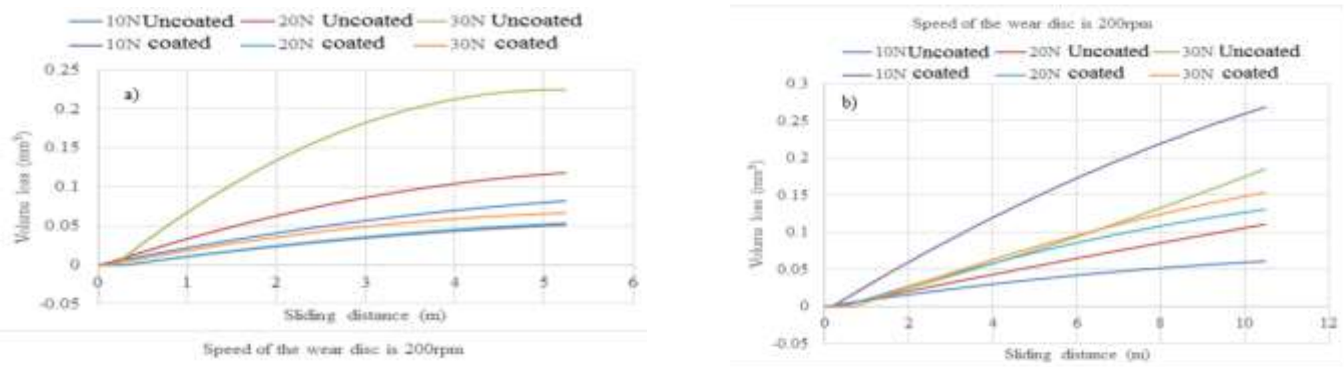

Fig 9 FEA resuts of wear volume loss as fuctnion of sliding distance at loads 10N,20N and 30N for uncoated and coated at a) 100 rpm and b) 200 rpm

4.1 Wear volume

Fig 9(a) shows the FEA results of wear volume loss due to wear vs sliding distance at speed of wear disc 100rpm, loads 10N, 20N and 30N for uncoated and coated. It can be seen that volume loss due to wear linearly increases with increase in sliding distance for both uncoated and coated and also the volume loss due to wear for coated specimen was lower compared to uncoated. This is because coating offers a lower contact area between pin and disc, and coating also improves the hardness of the surface when compared with uncoated surface. At 10N load the volume loss due to wear for uncoated is 0.0820mm^3 and for coated is 0.0514 mm^3 there was a reduction in volume loss of 37.31% for coated pin compared to uncoated pin. at 20N load the volume loss due to wear for uncoated is 0.1181mm^3 and for coated is 0.0536 mm^3,there was a reduction in volume loss of 54.61% and for 30N load the volume loss due to wear for uncoated is 0.2245mm^3 and for coated is 0.0664 mm^3 there was a reduction in volume loss of 70.42%.Fig 10(b) shows the volume loss due to wear vs sliding distance at speed of 200rpm, loads 10N,20N, and 30N for uncoated and coated. It can be seen that the volume loss due to wear linearly increases with with increase in sliding distance for both uncoated and coated and also the volume loss due to wear for coated specimen was lower compared to uncoated. This is because the coating offers a lower contact area between pin and disc, and coating also improves the hardness of the surface when compared with uncoated surface. At 10N load the volume loss due to wear for uncoated is 0.111mm^3 and for coated is 0.0608 mm^3 .There was a reduction in volume loss of 422% for coated pin compared to uncoated pin. At 20N load the volume loss due to wear for uncoated is 0.1861 mm^3 and for coated is 0.1305 mm^3 .There was a reduction in volume loss of 29.87% and for 30N load the volume loss due to wear for uncoated is 0.2689 mm^3 and for coated is 0.1535 mm^3 there was a reduction in volume loss of 42.91%.

4.2 Deformation of the Pin

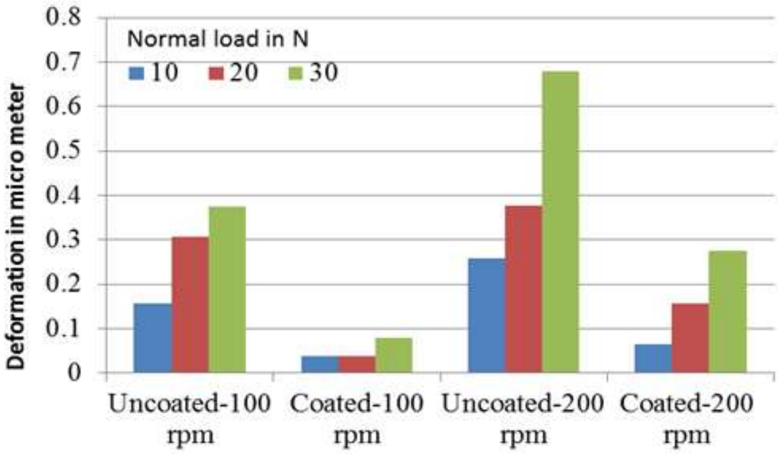

Fig.10 * Deformation of the pin at speed of wear disc 100 rpm and loads 10N,20N and 30N for uncoated and coated.

Fig 10 shows the deformation at speed of 100rpm and loads 10N,20N and 30N for uncoated and coated pin. It can be seen that deformation for uncoated and coated pin is increasing with increase in load and also the deformation for uncoated pin was higher compared to coated it is because coating improves the hardness and also the number of contacting

asperities is low for the coated pin the deformation for uncoated pin at load 10N was 1.5545x10^{-4} mm and for coated pin it was 0.36927x10^{-4} mm ,at 20N load the deformation for uncoated pin was 3.0723x10^{-4} mm and for coated pin it was 0.374 x10^{-4} mm at 30N load the deformation for uncoated pin was 3.7325x 10^{-4} mm and for coated pin it was 0.7875x10^{-4} mm. The deformation at a speed of 200rpm and loads 10N,20N and 30N for uncoated and coated pin it can be seen that deformation for uncoated and coated pin is increasing with increase in load and also the deformation of uncoated pin was higher compared to coated it is because coating improves the hardness of the pin and at load 10N was 2.5924x10^{-4} mm and of coated pin it was 0.6522x10^{-4} mm at 20N load the deformation of uncoated pin was 3.7735x10^{-4} mm and of coated pin was 1.5736x10^{-4} mm, at 30N load the deformation of uncoated pin was 6799 x10^{-4} mm and of coated pin was 2.7622x10^{-4} mm.

4.3: Comparison of Experimental and FEA results

The FE model was proved to be effective in predicting wear initiation and the trend of the FEA results will agree with the experimental results. The variation between the FEA and experimental results is 1 to 9% was observed. The Fig.11 concludes that contact analysis of wear in FEA and pin-on-disc experimental results showed increasing with the increasing normal load and sliding speed. They also showed that the wear volume decreases with DLC coatings of variation 6 to 31% at lower load and higher load respectively.

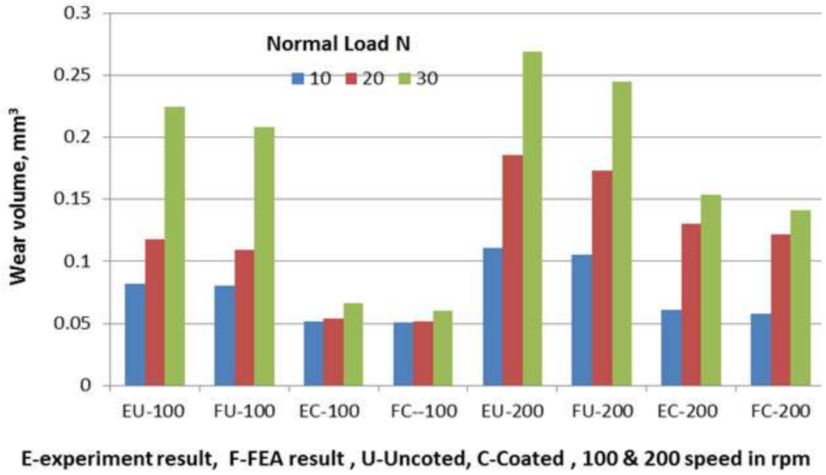

Fig. 11. Comparison of wear volume loss between experimental and FEA results

Conclusion

From wear analysis it was found that at a speed of disc 100 rpm the volume loss due to wear was lower for coated compared to that of uncoated specimen. The comparative volume loss between uncoated and coated at load 10N was 9%, at 20N it was 12.5 % and at 30N it was 31.4%. From wear analysis it was found that at speed of disc 200 rpm the volume loss due to wear was lower for coated compared to that of uncoated specimen. From wear analysis it was found that the deformation of coated pin is lesser compared to uncoated pin at speed 100rpm, 200rpm and loads of 10N, 20N and 30N. The uniform change in dimension due to wear is throughout the surface and hence the changes in dimensions taken across the contact area. The FEA wear analysis is predicted in nodal level than which was averaged across the contact. The developed FEA model was well agreed with experimental results.

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