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RESEARCH

Ni-Cr Based Self Lubricating Composite Performance for High Speed Engineering Application

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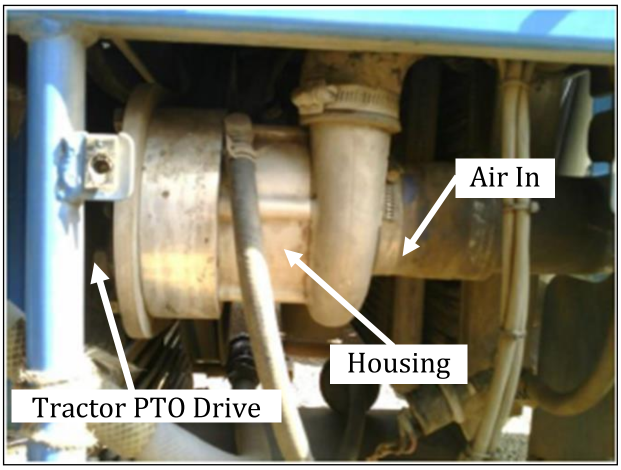
A B S T R A C T

Developed High speed-rotating machinery is used in agriculture for various processes. This machinery runs using the tractor PTO operated at variable speed. Operating systems of machinery were depends on the skill of the driver. Due to jerks during operation and lack of maintenance such machinery gets fails. To increase the life of rotating components, Ni-Cr based self-lubricating composite bearings were developed and used for the actual application. Self-lubricating composite was tested under the different velocities of 3.14, 3.77, 4.71, and 6.28m/s up to a maximum of 8 Hours. The average wear rate of 7.2%MoS_2 content composite is less than the other compositions of Ni-Cr-wt% of MoS_2 self-lubricating composite. The result of the actual trial shows that the average wear rate of Ni-Cr- 7.2 wt%MoS_2 at velocities 3.14m/s,3.77m/s,4.71m/s, and 6.28m/s is $5.74*10^{-9}mm^3/Nm$, $6.09*10^{-9}mm^3/Nm$, $6.30*10^{-9}mm^3/Nm$, and $6.44*10^{-9}mm^3/Nm$ respectively.

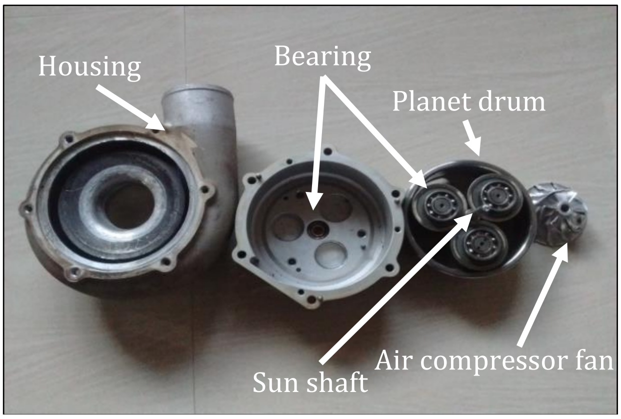
1. INTRODUCTION

Crop growth is essential in the agriculture sector and such improvement has been through liquid fertilizer or pesticide spraying. Pesticide spray device is driven using Power Take-Off (PTO) shaft of high Horsepower tractor. The central unit of the spray device is a high-speed turbocharger. A turbocharger is used to develop high velocity spray of pesticides to protect plants. One end of the turbocharger is driven with the tractor PTO and the other end is free to enhance the air velocity through the air compressor. The Assembly of this turbocharger is different from that of automobile turbocharger. Here instead of the exhaust gas turbine, input is taken from the tractor PTO shaft. Turbocharger working conditions vary based on different conditions like variation in input power, operating condition of a driver (Smooth or Hard use). The life of the turbocharger depends on proper lubrication and operating condition.

Fig. 1a shows the location of a turbocharger in the spray device. Fig. 1b shows the detailed components of the agriculture turbocharger, including housing, bearing, sun shaft, planet drum, solid bearing and air compressor fan.



(a)



(b)

Fig. 1. (a) Location of turbocharger in pesticide spray unit , (b) Components of turbocharger.

Various self lubricating composites were developed by researchers and tested for different parameters are reported in following contents. Also the primary studies related to tribological characteristics, coefficients of friction, and mechanical properties of these class of composites were arranged and reviewed in this section.

Kotkowiak et al. [1] developed Ni-20%CaF_2 self lubricating composite and sintered at 1200^{0}C temperature. Tribological analysis was done by using pin on disc method and tribofilm studied by using SEM and EDS techniques. With addition of CaF_2, wear rate is less than pure Nickel. Yang et al. [2] prepared MoS_2 containing microcapsule specimen using the double emulsion method and studied the performance of bearing for water lubricated bearing. Experimental tribological results of MoS_2 microcapsule were see to be superior in comparison to the composite containing MoS_2. Omrani et al. [3] developed the composite using Aluminium, Al_2O_3 and the graphene nanoplatelets. Graphene nanoplateletes is used as solid lubricant material. The developed composite gives coefficient friction of 0.2-0.25 and wear rate of $1*10^{-6}$ - $4*10^{-6}$ mm^3/Nm. Zhu et al. [4] worked on NiCr/hBN composite consisting of hBN as solid lubricant of around 8% to 12% by mass fraction. The optimum wear performance is obtained for 10% of hBN. Guo et al. [5] used Fe-Cu-Sn-Graphite in composition for development of self lubricating bearing and studied tribological properties against 40Cr counter material. Tests were conducted for 21 hours and result obtained showed presence of graphite on counter surface. Gupta et al. [6] reported work of Fe-C-Ni based self lubricating composite with addition of WS. Tribological performance is optimum for 9wt%, with 0.47 is coefficient friction and $1.5*10^{-3}$ g wear rate. Ravindran et al. [7] studied the effect of graphite wt% on Al hybrid composite by factorial design. It was observed that with increase in the graphite content in base composite, wear loss decreases.

Paris et al. [8] and Pradeep et al. [9] reported that the self-lubricating quality of the materials varies, depending on their homogeneity, the structure of the reinforcement, and the experimental friction condition. They also investigated the effect of applied load and temperature of composite, as it is important condition for selecting a particular application for researchers. Rukhande and Rathod [10] developed a NiCrBSiFe powder coating composite and compared it with 316L stainless steel as counter surface. Coefficient of friction is 0.15-0.68 for 300^{0}C to 700^{0}C temperature. The wear rate increases with increase in the NiCrBSiFe content.

Vuddagiri et al. [11] reported the effect of MoS_2 and Al_2O_3 in tribological behaviour of bearing. Composite manufactured using stir casting process was used in sliding test with sliding velocity and load of 2 m/s and 30N respectively. Coefficient of friction is seen to be low and the wear resistance improved in comparison with the base composition. Zhang et al. [12] developed a nanocomposite lubricant as tetrabutyl titanate and studied its performance. With addition of tetrabutyl titanate in base alloy, oil film strength increases up to 530 N and COF is obtained to be 0.087.

Renevier et al. [13] studied properties of the developed MoS_2 composite. They reported that the MoS_2 coating improved the co-deposition of small amounts of titanium and these coatings gave excellent results for wide application. Lu et al. [14] used Ni-based alloy/CeF_3/Graphite composite with varying graphite quantity and studied it against high-speed steel (W18Cr4V) as counterface material. Jian et al. [15] investigated and suggested suitable MoS_2 wt% with Ni-Cr-W-Ti-Al composite for better mechanical properties and minimum wear rate. In another similar investigation, Jian and Dang [16] also developed a self-lubricating composite for advanced jet engines, using Ni-Cr-Fe-W-Si, graphite molybdenum disulfide in varying percentage. Young et al. [17] worked on Ni-based composites incorporated with MoS_2 and Ag lubricating phase for wide temperature range application (RT to 700^{0}C). Qinling et al. [35] developed and studied different self-lubricating composites based on Nickel alloy, such as Nickel alloy-Graphite-Ag, Nickel alloy –WC/SiC-PbO, Nickel alloy-Ag-CeF_3, Nickel alloy–graphite-CeF_3 and Nickel alloy-MoS_2-Graphite. Bardeswaran and Perumal[18] studied effect of graphite wt% on Hardness and wear rate of aluminium graphite alloy, including Cu, Mn, Zn, Fe, Mg, Ti, Cr, and Si content. Ouyang et al. [19] studied the tribological properties of self-lubricant for high-temperature applications which is one of the challenging problems in the manufacturing of self-lubricant. Xiong [20] investigated the Ni-Cr-Mo-Al-Ti-B with MoS_2. The result obtained showed increase in mechanical and tribological properties of the material with the addition of MoS_2 up to 10wt%. Hodgson et al. [21], Vidal et al. [22], Zhang and Liu [23] developed a Co-Cr-Mo based composite and studied it in biomedical application for better corrosion resistance properties. Lingqian et al. [24] investigated ZrO_2 (Y_2O_3)-MoS_2-CaF_2 self-lubricating composite. Zhang et al. [25] developed Fe-Ni-based composite with addition of MoS_2/graphene that exhibited excellent mechanical properties. Yanjin et al. [26] studied the strength of Co, Cr, W alloy with and without the addition of Cu. and reported that the addition of Cu into the Co-Cr-W-based alloy did not affect the physical properties. Scharf et al. [27] developed the cobalt-based alloys consisting of Co, Cr, W, Ni, Mn, O, Fe, Si and C and studied its performance with the titanium alloy as counter material. Yuan et al. [28] studied the dry sliding wear behavior of Cu, Sn, Cu, Ag, and Cu, Mg alloys rubbing against Cr12MoV steel. Jia et al. [29] reported the study of Cu–Ag self lubricating composite for electrical train pantograph.

The above literature shows that researchers used different type of composition wt% and tested them under different condition and suggested limitation of composite wt% for the excellent friction or wear rate under the sliding velocity or working load. Therefore tremendous scope is available for development of self lubricating composite for agriculture high speed application.

2. CASE STUDY FOR DECIDE THE PARAMETERS AND SELECTION OF SELF LUBRICATING COMPOSITION

For parameter/ data selection, a trial of agriculture pesticide spraying unit was conducted for 63 minutes under the steady position of the machine at 24^{0}C surrounding temperature and 0.6 m/s air velocity as during test. For agriculture pesticide spraying, maximum pressure is the criteria. For pressure, adjustment is needed to increase or decrease the speed of the tractor PTO shaft. Speed of PTO changes with tractor gear ratio. The speed ratio of the PTO shaft to the turbocharger shaft is 1:7. For different gear conditions, shaft velocity and air mass flow rate recorded for the turbocharger is as per the Table 1.

Table 1. Parameters based on actual trial of pesticide spray with tractor.

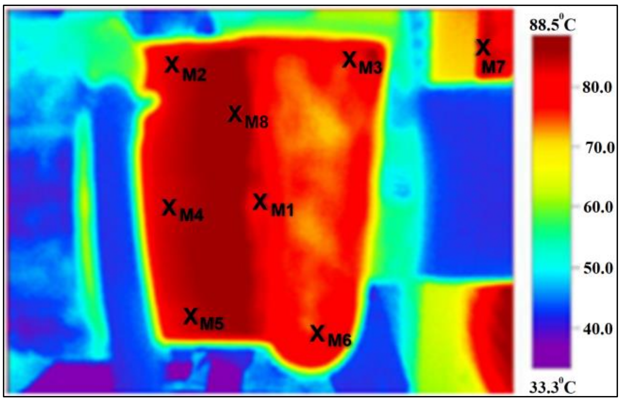
Gear position	Speed of PTO shaft (rpm)	Shaft speed (rpm)	Velocity of shaft (m/s)	Air mass flow rate (kg/s)
1	1430	10000	3.14	0.018
2	1700	12000	3.77	0.022
3	2150	15000	4.71	0.027
4	2850	20000	6.28	0.036

The temperature of turbocharger housing recorded at different speed as per following Table 2 by using the thermal camera. Thermal camera collects random point reading and shows the highest temperature reading as hot spot.

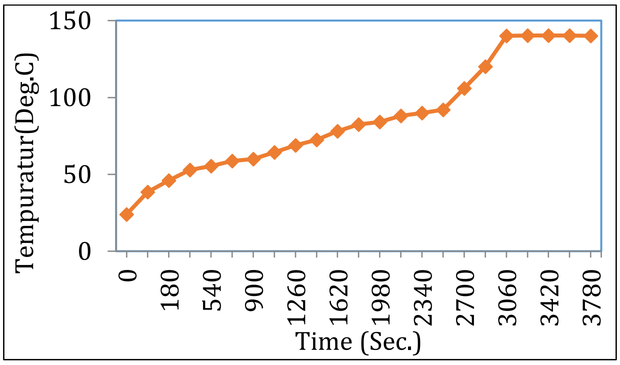
Table 2. Temperature of turbocharger housing.

Speed of PTO shaft (rpm)	Duration in second	Temperature of housing (^{0}C)
1430	360	56.7
1700	1140	63.81
2150	2160	80.4
2850	3240	138.6

Fig. 2a shows the thermal image of turbocharger housing at input speed 2150 rpm and recorded at 2160 seconds after running the unit.



(a)



(b)

Fig. 2. (a) Thermal image of turbocharger housing, (b) Temperature of housing with respect to time.

With increase in the speed of machine, the temperature of turbocharger housing gradually increases as shown Fig. 2a and it is stable after 3060 sec at maximum PTO shaft speed of 2850 rpm as shown Fig. 2b.

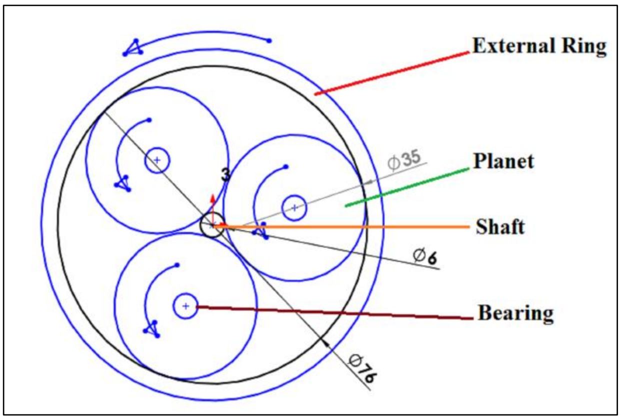
2.1 Calculation for cylinder contact

As per Hertz's theory, deformation and stress are calculated for cylindrical shape for Fig. 3a and 3b using Equation 1 to Equation 7 [33-34].

Material for the components shown in Fig. 3a is stainless steel with modulus of elasticity 193-200GPa and Poisson's ratio 0.27-0.28.

b = contact half-width

$$b=\sqrt{\left(\frac{2F}{l}\right)\left(\frac{\left(1-v_1^{\,2}\right)/E_1+\left(1-v_2^{\,2}\right)/E_2}{1/d_1+1/d_2}\right)} \tag{1}$$



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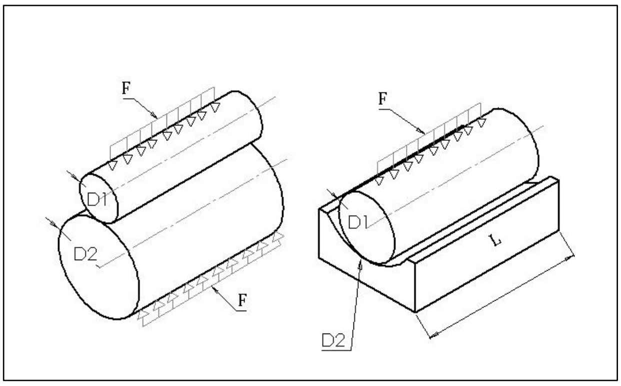


(b)

Fig. 3. (a) Arrangement of cylinder in turbocharger, (b) Hertz's theory diagram for cylinder[33-34].

P_{max} = Maximum pressure

$$p_{\max}=\frac{2F}{\pi bl} \tag{2}$$

σ_x =Principal stress

$$\sigma_x=-2vp_{\max}\left[\sqrt{\left(1+\frac{z^2}{b^2}\right)}-\left|\frac{z}{b}\right|\right] \tag{3}$$

σ_y = Principal stress

$$\sigma_y=-p_{\max}\left[\frac{1+2\frac{z^2}{b^2}}{\sqrt{\left(1+\frac{z^2}{b^2}\right)}}-2\left|\frac{z}{b}\right|\right] \tag{4}$$

σ_z = Principal stress

$$\sigma_z=\frac{-p_{\max}}{\sqrt{\left(1+\frac{z^2}{b^2}\right)}} \tag{5}$$

τ_{xz} =Shear stress

$$\tau_{xz} = \frac{\sigma_x - \sigma_z}{2} \qquad (6)$$

τ_{yz}=Shear stress

$$\tau_{yz} = \frac{\sigma_y - \sigma_z}{2} \qquad (7)$$

Table 3. List of parameters.

Symbol	Parameter	Symbol	Parameter
F	Applied force	d1, d2	Object-1,2 diameter
v1, v2	Object-1,2 Poisson's ratio	z	Depth below the surface
E1, E2	Object-1,2 elastic modulus	l	Contact length of cylinders

Table 4 shows the Contact stresses for external ring and planet.

Table 4. Contact stresses for ring and planet.

Parameter	Obj-1	Obj-2	Obj-1	Obj-2	Obj-1	Obj-2	Obj-1	Obj-2
	25N		60N		120N		160N	
Maximum Hertzian contact pressure [pmax] (MPa)	58.7		91		128.7		148.6	
Max shear stress [τmax] (MPa)	17.6		27.3		38.6		44.6	
Depth of max shear stress [z] (mm)	0.011		0.017		0.023		0.027	
Rectangular contact area width [2b] (mm)	0.027		0.042		0.059		0.069	

Table 5 shows the External pressure for planet and shaft.

Table 5. External pressure and contact stresses on planet and shaft.

Parameter	Obj-1	Obj-2	Obj-1	Obj-2	Obj-1	Obj-2	Obj-1	Obj-2
	25N		60N		120N		160N	
Maximum Hertzian contact pressure [pmax] (MPa)	127.5		197.6		279.4		322.7	
Max shear stress [τmax] (MPa)	38.3		59.3		83.9		96.9	
Depth of max shear stress [z] (mm)	0.005		0.008		0.011		0.012	
Rectangular contact area width [2b] (mm)	0.012		0.019		0.027		0.031	

3. COMPOSITE PREPARATION AND EXPERIMENTAL SETUP

Table 6 shows the composition of Ni-Cr based self lubricating composite were developed by using powder metallurgy process under 330MPa compacting pressure and 1000^0C sintering temperature.

Table 6. Self lubricating composite compositions.

Composite name	Matrix (wt %)	Reinforcement (wt %)					Binder (wt%)	
	Ni	Cr	Co	Si	MoS_2	Cu	W	PVA
Ni-Cr-5 MoS_2	Balance	24	12.25	1.75	5	3	2	0.25
Ni-Cr-6.5 MoS_2	Balance	24	12.25	1.75	6.5	3	2	0.25
Ni-Cr-7.2 MoS_2	Balance	24	12.25	1.75	7.2	3	2	0.25
Ni-Cr-10 MoS_2	Balance	24	12.25	1.75	10	3	2	0.25

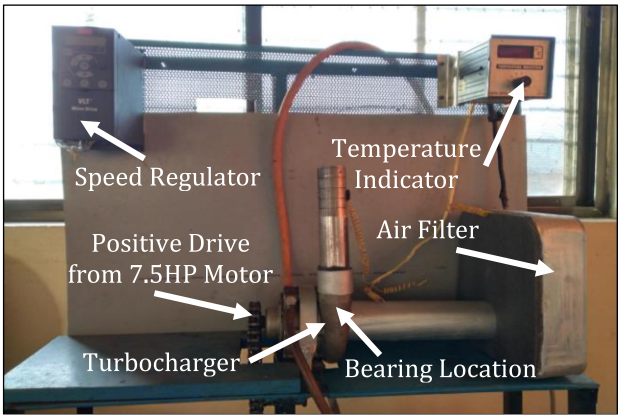


Fig. 4. Actual experimental calibrated setup.

Fig. 4 shows the experimental setup used for finding the wear rate of developed Ni-Cr-MoS_2 self-lubricating composite against the EN-32 shaft. Agriculture machine turbocharger is used to study the performance of manufactured self-lubricating composite and manufactured shaft. Fig. 5 shows the detail construction of the machine shaft (counter material), EN32 is 0.574µm and 285 BHN Roughness and hardness respectively, having dimensions Ø6 mm * 67.5 mm and Fig. 6 shows the developed specimens. In this Figure 6, A shows the Specimen after the sintering process, B shows the cleaned specimen which was used for calculating mechanical and tribological properties(Pin on Disc) and Fig. C shows solid bearing which was used for actual trial having dimensions are Hole Ø6mm* Outer Dia.30* and Thickness 20 mm.

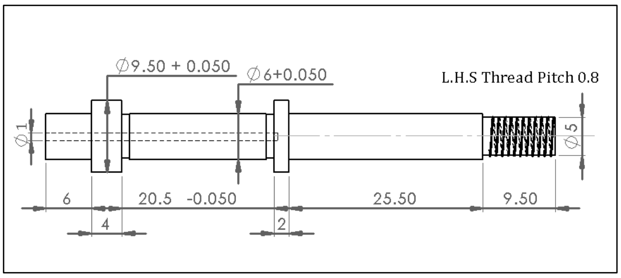
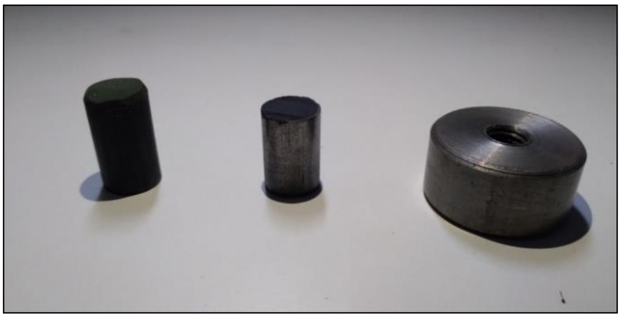


Fig. 5. Shaft geometry.



(a) (b) (c)

Fig. 6. Solid bearing and specimen.

To obtain the wear rate of Ni-Cr-MoS_2 based self-lubricating composite following steps were used:

1. Initially, bearing weight is measured using a calibrated weighing balance (WENSAR Make, Model: PGB 200, Max: 200gm d: 0.001gm), and then it is fixed in position.

2. Test is conducted four times for finding wear of developed bearing. The machine is operated for the stipulated period as 0 to 2 hours, 0 to 4 Hours, 0 to 6Hours and 0 to 8Hours for velocities of 3.14 m/s, 3.77 m/s, 4.71 m/s, and 6.28 m/s in different batches at surrounding temperature 28^{0}C.

3. After testing, the developed bearing as shown Fig.6C was removed from its position and cleaned using acetone for noting its mass and the wear rate was calculated based on mass difference.

4. For every reading, a new solid bearing is used as shown composition shows in Table 6, and the wear rates of the composite were calculated based on mass difference. The temperature of the setup housing is recorded at the end of each trial using a thermal camera. (Testo-872, Serial: 60856461, Version: 1.5.1., Range 0^0 C to 650^{0}C).

4. RESULTS AND DISCUSSION

4.1 Mechanical properties of Ni-Cr-MoS_2 based self-lubricating composite

A mechanical property of developed composite was calculated as per ASTM standards. With increase in the wt% of MoS_2, Hardness and Density of developed composite increases, however porosity decreases as shown in Table 7.

Table7. Mechanical properties of Ni-Cr-MoS2 based composite.

Composite contents (wt%)	Vickers hardness (HV) (Min.and Max.)	Density (g/cm^3)	Porosity (%)
Ni-Cr-0 MoS_2	201-230	6.895	2.012
Ni-Cr-5 MoS_2	208-245	6.442	1.865
Ni-Cr-6.5 MoS_2	223-258	6.954	1.896
Ni-Cr-7.2 MoS_2	241-269	7.145	1.623
Ni-Cr-10 MoS_2	271-312	7.213	1.731

4.2 Wear rate of Ni-Cr-MoS_2 self-lubricating composite based on actual experiment performance

Fig. 7 shows the variation of wear for Ni-Cr-5wt% MoS_2 developed self-lubricating composite for the different shaft velocities. The wear rate of composite for 3.14m/s and 6.28 m/s test after 04 hours and 06 hours test has slightly decreased.

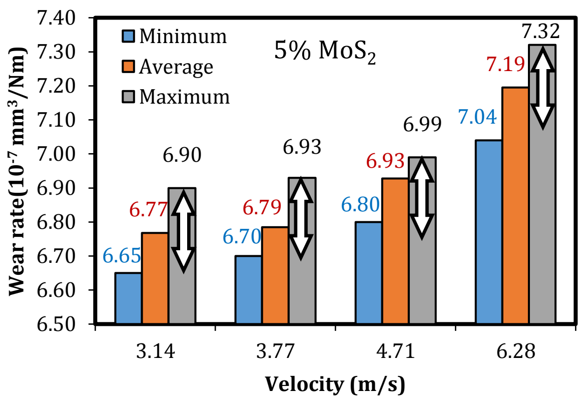


Fig. 7. Wear rate analysis of 5% MoS_2 content bearing.

However, after increasing test duration to 08 hours, wear increases. The average wear rate for 3.14 m/s and 6.28 m/s test is obtained to be 6.77*10^{-7}mm^3/Nm and 7.19*10^{-7}mm^3/Nm. In another test condition, with velocity of 3.77

m/s and 4.71 m/s, wear linearly increase for the 02 hour duration test, then decreases for 06 hour duration test and again increases for the 08 hour test. The average wear rate for velocity 3.77 m/s and 4.71 m/s is 6.79*10^{-7}mm^3/Nm and 6.93*10^{-7}mm^3/Nm respectively. With the addition of 5wt% MoS_2 in Ni-Cr self-lubricating composite, minimum average wear 6.77*10^{-7}mm^3/Nm is obtained with 3.14 m/s velocity test as compared to other velocity condition. Ni-Cr-based composite gives best performance with 5wt% MoS_2 present for all velocities for 06 hours duration test.

For another composite 6.5 wt% of MoS_2, wear was calculated for the same velocity as 3.14m/s, 3.77m/s, 4.71 m/s, and 6.28 m/s with 02-hours time duration up to 8 hours. Fig. 8 shows the variation of wear present 5.40*10^{-8} mm^3/Nm, 5.55*10^{-8}mm^3/Nm, 5.69*10^{-8}mm^3/Nm, and 5.86*10^{-8}mm^3/Nm, respectively. In comparison with 5wt%MoS_2, wear of 6.5wt% MoS_2 is slightly increased for the same test condition.

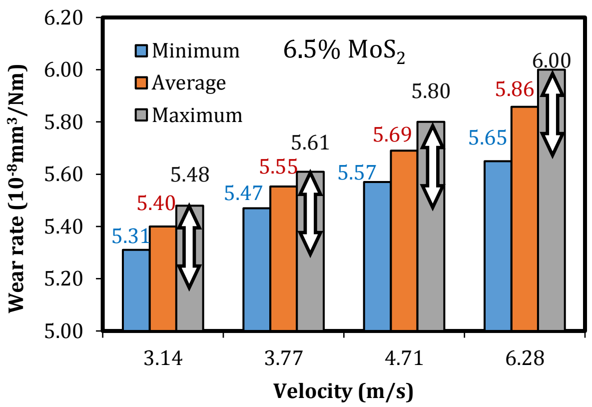


Fig. 8. Wear rate analysis of 6.5% MoS_2 content bearing.

Fig. 9 shows the wear rate of Ni-Cr-based self-lubricating composite for 7.2 wt% MoS_2. Wear for such composition is approximately the same up to 06 hours test duration time for respective velocity, while after 06 hour test, wear rate is linearly increases and its maximum at 08 hour test. The average wear rate of 7.2%MoS_2 content composite is less than the other compositions of Ni-Cr-wt% of MoS_2 self-lubricating composite. Average wear rate of Ni-Cr-7.2wt%MoS_2 at velocity 3.14m/s,3.77m/s,4.71m/s and 6.28m/s is 5.74*10^{-9}mm^3/Nm, 6.09*10^{-9}mm^3/Nm, 6.30*10^{-9}mm^3/Nm and 6.44*10^{-9}mm^3/Nm respectively.

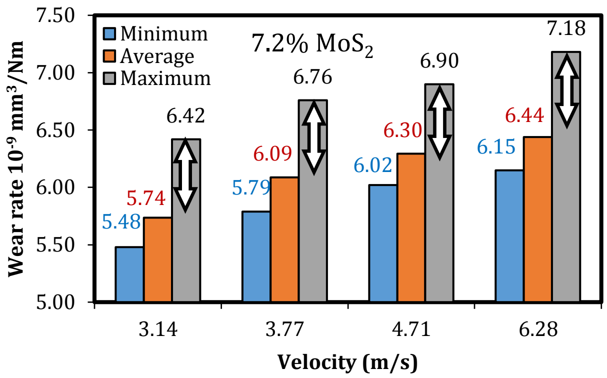


Fig. 9. Wear rate analysis of 7.2% MoS_2 content bearing.

With the addition of 10 wt% MoS_2 in a based Ni-Cr composite, wear rate is more than the other composite of MoS_2 wt%. For 3.14m/s shaft velocity, it is 7.62*10^{-5}mm^3/Nm and this wear is comparatively less than another velocity for the same wt% composition. The maximum wear rate 1.04*10^{-4}mm^3/Nm is noted for 6.28m/s high-velocity. Fig. 10 shows the average wear rate for 8 hours of test time.

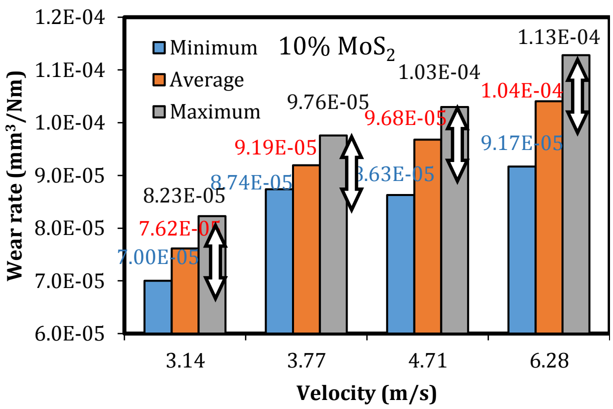


Fig. 10. Wear rate analysis of 10% MoS_2 content bearing.

It is observed that increasing MoS_2 content in composite decreases the coefficient of friction for all load conditions and velocity. Hence, the tribological performance of composite increases due to decreasing coefficient of friction between developed composite and EN32 due to creation of the lubricating layer between these surfaces.

4.3 Microstructure analysis of hollow cylindrical bearing after wear

Microstructure of bearing taken after the continuous run of 8 hours, for Ni-Cr, MoS_2 based composite for different velocity and wt% of MoS_2 as shown in following Fig. 11 to Fig.14.

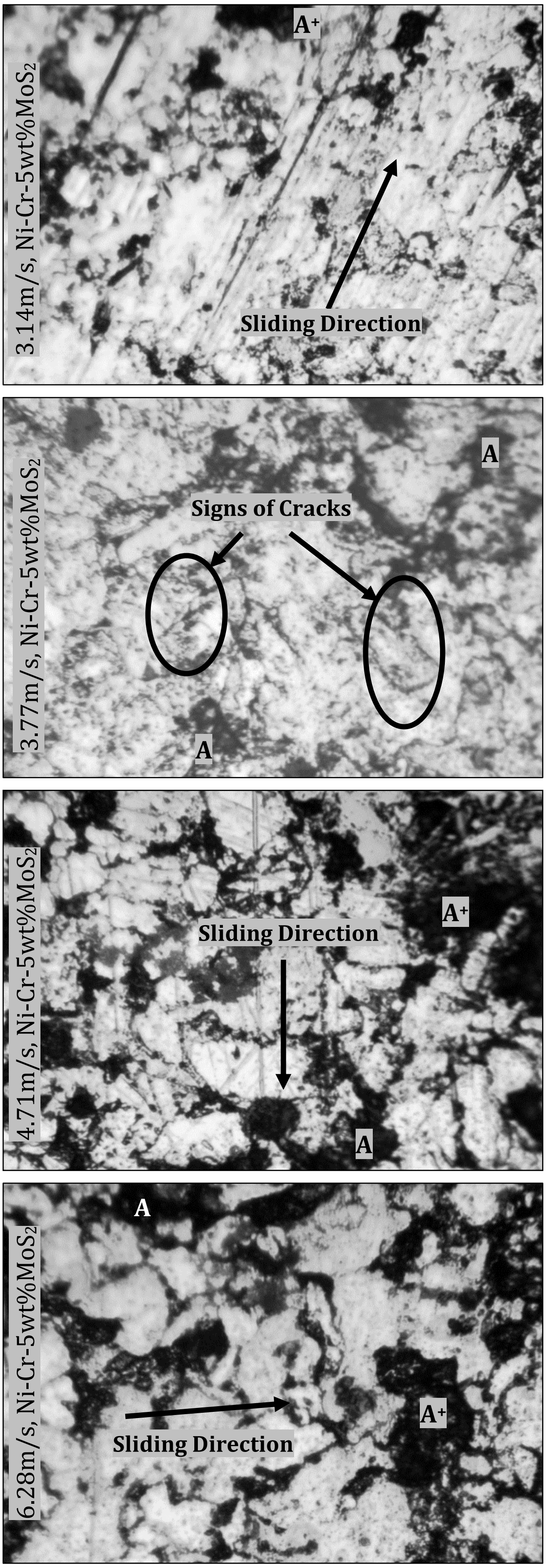


Fig. 11. Microstructure of Ni-Cr-5wt%MoS_2 composite bearing after test.

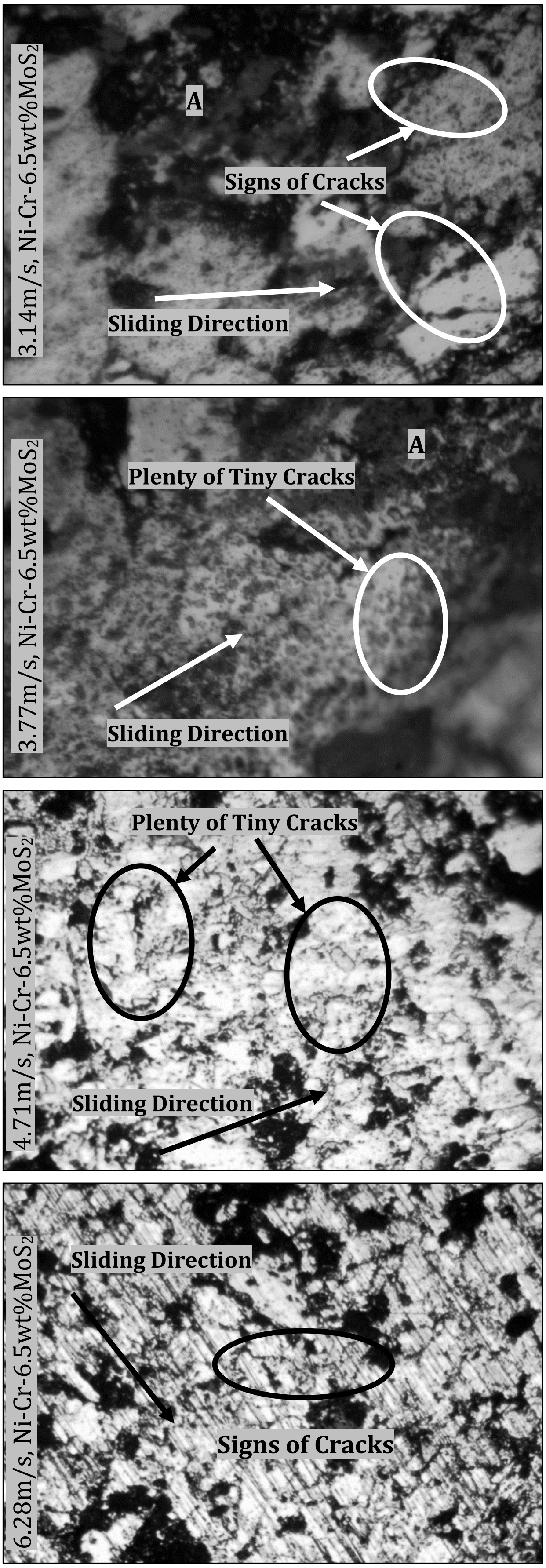


Fig. 12. Microstructure of Ni-Cr-6.5wt%MoS_2 composite bearing after test.

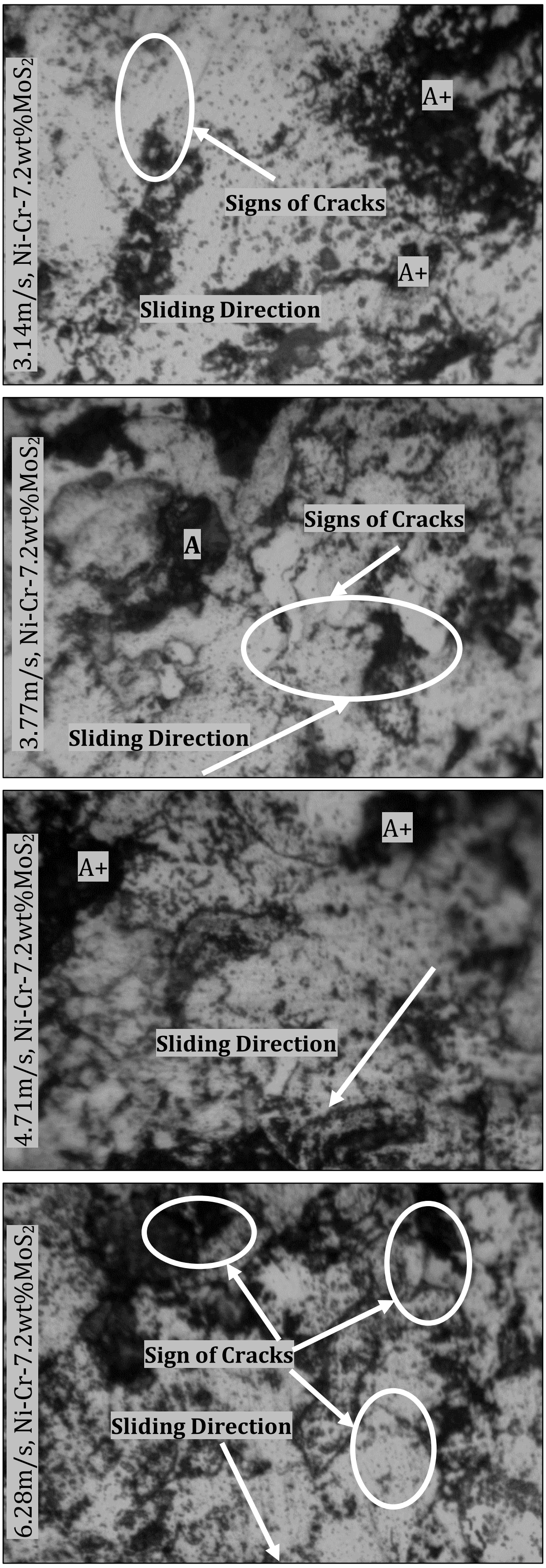


Fig. 13. Microstructure of Ni-Cr-7.2wt%MoS_2 composite bearing after test.

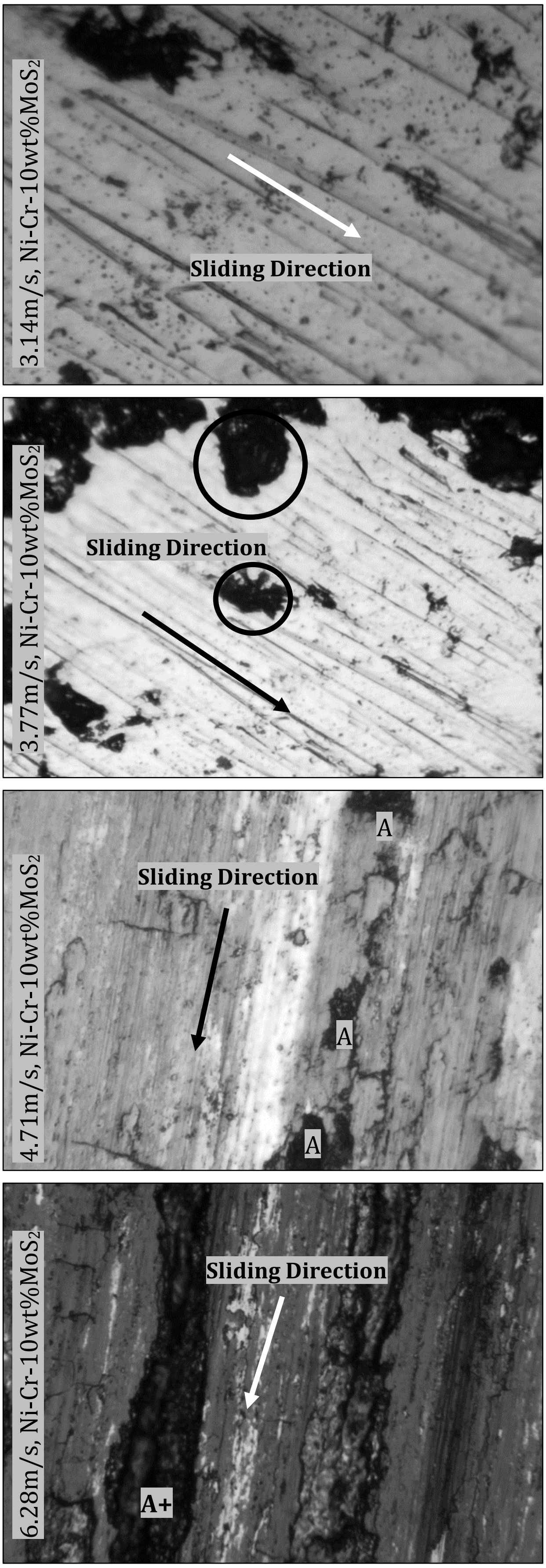


Fig. 14. Microstructure of Ni-Cr-10wt%MoS_2 composite bearing after test.

Bearing surfaces of Ni-Cr 5wt%MoS_2, Ni-Cr 6.5wt%MoS_2, Ni-Cr 7.2wt%MoS_2, and Ni-Cr 10wt%MoS_2 shows almost the same worn out. Only the surface of bearing having 7.2wt% MoS_2, as shown in Fig. 13, is different from other surfaces. On these surfaces, lubricating films are formed as marked as A and A+. Based on the observed reduction in wear rate as reported in this paper, it can be argued that a lubricating film is formed over the bearing surface. Evidence in the literature also supports this claim. For 10wt% MoS_2, such a lubricating layer of the surface is considered responsible for the lower wear and friction rate.

The direction of sliding and cracks position is marked in Fig. 14 and some delamination and plastic deformation are noted. Such delamination and plastic deformation are maximum for the 10wt% of MoS_2 self-lubricating composite than other compositions. Similar results were reported by Liu et al. [30] for MoS_2 based composite material on the friction surface. They observed plastic deformation on friction surface and this resulted in increase in the wear rate of material. In another study, Mohammad et al. [31,32] reviewed the use of MoS_2 in different composition for various tribological parameters and described that a transfer film (self lubricating layer) is created on the counter surface. They also reported that MoS_2 solid lubricants within other alloys provide the best friction and wear resistance at room temperature condition.

4.4 Turbocharger housing temperature analysis

During every trial, temperature of the bearing housing was recorded using a thermal camera (Testo-872, Serial: 60856461, Version: 1.5.1., Range 0^0 C to 650^0C)), as shown in Fig. 15

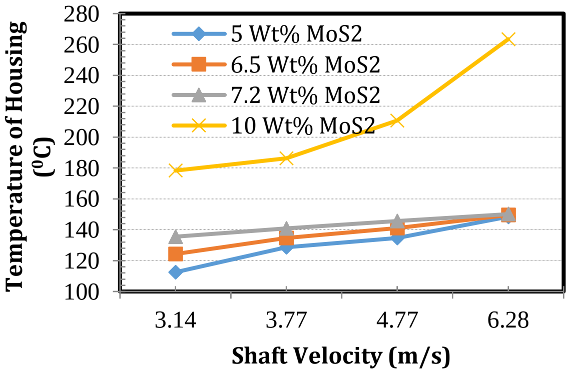


Fig. 15. Temperature of bearing housing for different bearing material against shaft velocity.

The temperature of turbocharger housing for 10wt% MoS_2 self-lubricating composite test it is greater than other compositions as shown in Fig. 15. There is no provision to find out the COF of surfaces in the actual experimental setup as shown Fig. 5. The temperature of the experimental setup housing, as seen in Fig. 15, is also more remarkable for 10wt% MoS_2 than the other composition due to the presence of delamination and plastic deformation on the surface.

5. CONCLUSION

NiCr based self-lubricating composites were developed by powder metallurgy process under the pressure of 330MPa and sintering at 1000^0C up to 2 hours holding temperature under Aragon as inert gas.

Developed composite used for calculate wear rate and morphological analysis after the test. The main results of Ni-Cr base composite experimental study were summarized in the following.

1. Ni-Cr 7.2wt% MoS_2 shows the excellent result of tribological performance against the EN32 material for different velocity
2. The minimum wear rate obtained for Ni-Cr-MoS_2 composite at 7.2wt% MoS_2 is 10^{-9} mm^3/Nm and for different sliding velocities as 3.14, 3.77, 4.71 and 6.28m/s. The wear rate of composite increases with increase the sliding velocity of counter material. This shows that the wear rate was optimum with the 7.2 wt% MoS_2 addition to the base Ni-Cr-C0-Cu-Si-W elements.
3. The tribological performance of the developed self-lubricating bearing by using experimental study shows a minimum wear rate of $6.44*10^{-9}mm^3/Nm$ for 7.2 wt% of MoS_2 in the composite. Further addition of MoS_2 to 10 wt% increase wear rate to $1.04*10^{-4}$ mm^3/Nm. The improvements in tribological properties are attributed to the tribo-chemical reaction and the lubricating layer, which is obtained between base alloy and MoS_2 during the rubbing process.
4. The friction coefficient of adhesion is velocity dependant and decreases linearly with MoS_2 contents in Ni-Cr-based composite. There is a good agreement between the pin-on-disk tribometer and the experimental result.

5. Lubricating layer were observed after the wear analysis, and such surface is responsible for the lower wear and friction rate. Delamination and plastic deformation are maximum for the 10wt% of MoS_2 composite than the other composition.

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