ISSN: 0971-1260
Vol-22-Issue-17-September-2019

A Critical Review on Mechanical and Wear Properties For Advance Materials

Subhash[a], UpinderKumar[b], SandeepKumar[b]

aM. Tech Scholar, School of Mechanical Engineering, Lovely Professional University, Phagwara-144411, Punjab, India

b Assistant Professor, School of Mechanical Engineering, Lovely Professional University, Phagwara-144411, Punjab, India

Corresponding author e-mail: upinder.17973@lpu.co.in

Abstract: Owing to the economical loses of manufacturing and production industries because of inadequate wear leads to the path way of current study. Moreover, improvements in mechanical properties are equally responsible in order to achieve higher production ability and manufacturability. Current study is a critical analysis of numerous advanced material regarding their mechanical and wear properties. Advanced wear resistance material defines their properties with different reinforcing agents. Effect on the mechanical and wear properties due to different reinforcement phases are analysed in this paper. Improve the mechanical properties of aluminium, grapheme, VN alloy and different thermoplastics through various coating. Effect on the wear rate and wear resistance due to several factors like sliding velocity, sliding time and load factor. Wear rate has a considerable effect in the life of machine tools and also enhance the manufactured product quality.

Introduction: Nowadays automobile industries are developed advanced materials due to increasing demand for fuel efficiency, light weight etc. along with optimized structure design. Metal matrix composites are usually used in industries because of better mechanical and wear resistance properties. The manufacturing cost and fibre cost of Particulate-reinforced composites as compared to fibre-reinforced composites. Particulatereinforced composites ought to be isotropic in nature and, therefore,their processing can be done through conventional methods used for metals. Automobile industries used silicon carbide reinforced aluminium composites for brake rotors,cylinder heads, calibres, liners and pistons [1, 2].

Industries are facing wear challenges, which decreases the tool life and life of machine parts, produced low qualities materials, increases the cost of maintenance. Wear properties depends upon the phases of metal work and metal strength. Some methods are used to increase the wear resistance such as solicitation of maintaining the load, reduced speed and temperature, lubricant, selection of alloy. Wear also decrease the wear rate due to create coolant chamber, contain water and reduce the friction between the contact surfaces [3, 4].

Aluminium alloy 6000 series material used to manufacture the cylinder blocks, crankcase and pistons. Normally steel, aluminium alloy and cast-iron materials are used to manufacturing the cylinder block and pistons. Wear generally absorbs by these components because of friction, these parts work continuously with IC engine. Maximum these components manufactured by high strength structure and high energy absorb material. For increasing the life of IC engine generally used coating to developed high wear resistance and high hardness [5]. Combination of SiC particle and Al-Si alloy decreased wear rate and found that wear

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

resistance increases with reinforcement percentage [6]. Cold spray is a solid state method and variety of thermal spray method. In this method addition of spray particles using supersonic velocity below the spray melted temperature. Cold spray technique used in industries for avoid wear. Cold spray components used in aerospace, energy plant and automobile [7,8]. Fretting test is used for wear test with highly precision value at room temperature. Wear resistance improved by increasing the hardness [9].

Aluminium Matrix Composites

Aluminium Matrix Composites used to manufacture bearings, brushes and contact strips in industries. With aluminium alloy various reinforcing particles such asAl_3Ti, $Al_2O_3$and SiC have been utilized via friction stir processing. Due to addition of reinforcement improve the mechanical properties as well as reduced wear rate [10,11]. Al7075 alloy has high toughness value and strength value but there is limitation, has poor resistance. Metal matrix composite fabricated by vacuum stir casting technique. This report found that increase the reinforcement particle, decreases the material loss [12].

Al6082 alloy with 5% SiC compared with 5%TiB_2 reinforcement. The author has done the wear behaviour test at different loads and sliding speeds. The mass loss from mating parts, dimensions changes at mating parts and it leads to failure of parts in industries. This report found that TiB_2 has better wear resistance properties than SiC [13].

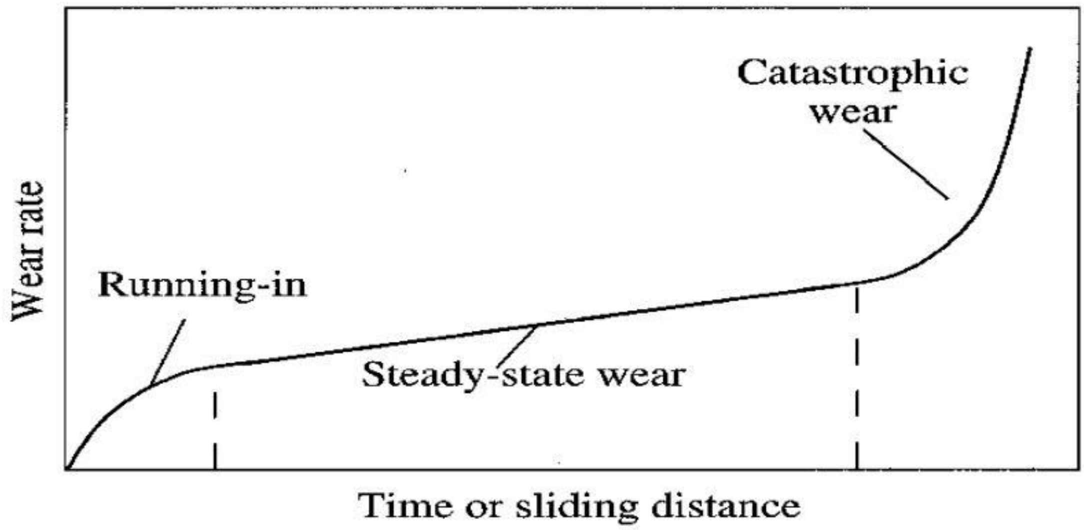

Figure 1: Wear rate vs Time or sliding distance [12]

Graphite coating on Aluminium piston

Graphite coating by screen printing technique on aluminium material piston has been done. To observed the surface morphology via scanning electron microscope (SEM). After the graphite coating, SEM test show the asperity (crests and troughs) on surface of piston. During the working of piston, troughs help in storing the oil lubricant. The Oil lubricant reduced the wear on piston. The crests and troughs between the cylinder bore surface and graphite coatingdamage the surface veracity for the cylinder core. Graphite coating expands on

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

surface with constant thickness measured via ultrasonic thickness gauge. During the piston work graphite particle convert into lubricant and help to storage the oil lubricant and increase the lubrication properties. Graphite coating reduce the friction value between the piston and cylinder core. The wear properties of aluminium metal matrix (MMCs) coating with grey cast iron have been compared. Wear test applied on pin-on-disc device. Stir casting method was used to manufactured Al disc consider 25%SiC. MMCs materials have very high wear resisting properties ifmatched with grey cast iron. Friction coefficient has been reduced while increasing the loading in both materials. MMC's materials have 25% morefriction coefficient than grey cast iron [14-17].Graphite coating region is shown in figure 2.

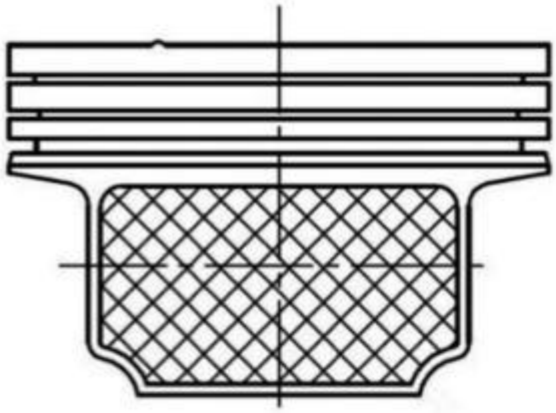

Figure 2: Graphite coating region [15]

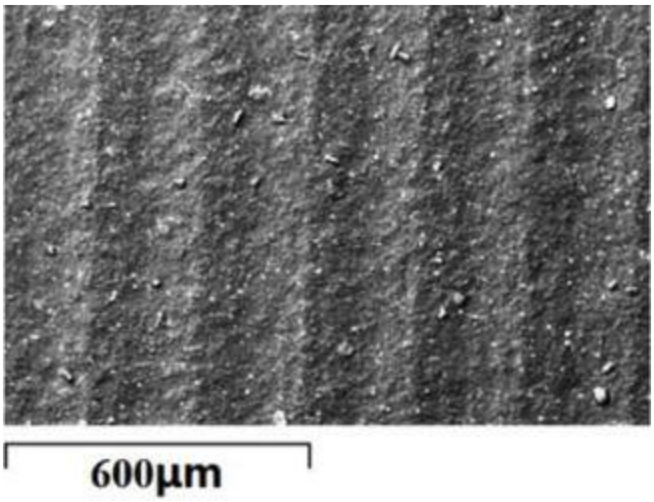

Figure 3: SEM Morphology [15]

Scanning electron microscope lens (SEM) is one of the basic tactics for imaging the microstructure and morphology of the ingredient metals. In SEM, an electron pillar with low vitality is emanated to the material and sweeps the outside of the example. A few unique connections happen as the bar reaches and enters the material, which lead to the emanation of photons and electrons from or close to the example surface. So as to frame a picture the accepting sign created from the electron–test connections are recognized with various sorts of identifiers relying upon the method of SEM being utilized. Various methods of SEM exist for portrayal of materials (counting biomaterials, for example, the X-beam mapping, optional

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

electrons imaging, backscattered electrons imaging, electron diverting, and Auger electron microscopy[15].

Table 1: Properties of different materials with their properties

Materials	Properties	References
Graphene	Ultra-thin thickness Remarkable mechanical properties, lubricity as well as high wear resistivity To enhance tribological properties used as reinforcing phase	16
Al7075	High strength and toughness Poor wear resistance	17
Al6061	Heat treatability Improved toughness and corrosion resistivity High mechanical strength and structure	18
TiB_2	High melting point High oxidation resistance and hardness Low density Exceptional wear resistance	19
Zirconium Carbide (ZrC	Low fracture toughness Excessive porosity High melting temperature Excellent corrosion and resistance	20
Zirconium oxide (ZrO_2)	Excellent mechanical properties Excellent thermal properties Excellent electrical properties Low thermal conductivity	21
Titanium Oxide (TiO_2)	Absorb Ultra-violet light radiation	22
Al-Sn alloy	Excellent tribological properties Excellent mechanical properties Self-lubrications	23
Co based alloy	Improved strength Improved hardness and oxidation resistivity Improved wear resistivity	24-27
MoS_2	High compressive strength High bonding strength High temperature strength Low friction coefficient	28-29
Al_2O_3	Excellent hardness High thermal conductivity Chemical inertness Low thermal expansion	30
SiC	Lightness High hardness value Improved thermal conductivity Reduced thermal expansion	30

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

Material	Component	Action	References
Aluminum	Mg_2Si/Al, phosphorus	Wear rate increases with increases sliding velocity and load. Surface temperature increases	33
Hypereutectic Al-Si Alloy	Mg_2Si/Al	High temperature of melting, High elastic modulus and hardness low thermal expansion coefficientLow density	34
Al-Si Alloy	SiC	Increase wear resistance with increased reinforcement Decrease wear rate	35
Aluminum	Metal matrix	Increase strength and density ratio Increase stiffness and density ratio Excellent fatigue resistance Very low thermal expansion coefficient Excellent wear resistance	36
Al7075	Al2O3	With increased the reinforced decreased the wear	37
AA6082	TiB2	More extreme wear with higher load Better wear resistance	38
AA6063 aluminum alloy	Tungsten Carbide	Improved the hardness Improved the wear properties	39
Zirconium Carbide (80%)	Titanium Carbide (20 %)	High hardness High fracture toughness	40
Ceramic	Zirconium Oxide	Improved hardness and toughness	41,42
Graphene	$Al2_2O_3$	Increases bonding strength, lubricity Increased toughness Excellent wear resistance Decreased wear rate	43

Table 2: Different materials with different reinforcement

Table 3: Mechanical and Wear properties of Graphene [16]

Graphene (wt%)	Porosity (%)	Bonding strength (MPa)	Hardness (HV)	Steady state friction coefficient (10N)	Wear rate ($10^{-3}mm^3N^{-1}m^{-1}$)
0	4.30	20.308	1132	0.58	4.4
3	3.06	24.572	1128	0.42	4.2
6	2.80	32.970	1189	0.40	3.28
9	5.85	26.943	1104	0.25	4.94
12	7.26	18.581	1060	0.34	5.3

VN Alloy with Co-based alloy

Laser cladding technique used for directly deposited the additional materials on substrate to increase the hardness, wear resistance and temperature resistance. Additional material deposited via pre-placed powder particle. Drawback of this technique is how to stop defects in coating or avoid cracking [44-47]. The author selected the VN alloy material with Co based alloy coating to investigate the wear resistance and microstructure through laser cladding technique. The report improved the hardness and wear resistance properties by adding the VN alloy [48-49].

Thermoplastic polymers

Thermoplastic polymers are usually utilized for Tribal applications due to internal restraining capacity, self-lubricating nature and have ability to work in abrasive atmosphere. Semi-crystalline polymers also contain amorphous regions which encapsulate crystals as a matrix representing the degree of crystallization. Degree of crystallinity depends upon the thermal and mechanical predecessor of polymers and has effect on mechanical properties. Due to changes in orientation structure and properties of molecular chains, the degree of crystallinity effects on the behaviour and transfer layer formation. Which effect on friction and wear properties [50-53]. The mechanical properties of amorphous and semi-crystallinities thermoplastics under 4MPa pressure and 50mm/s speed shown in figure below. These different polymers are Shown in table 4. The wear rate and friction values different polymers at different temperatures values shown in table 4.

PC	Polycarbonate
PEI	Polyether-imide
PAI	Polyamide-imide
PPSU	Poly-phenylsulfone
PET	Polyethylene terephthalate
PPS	Polyphenylene Sulphide
PA6	Polyamide 6
UHMWPE	Ultra-high molecular weight Polyethylene
PVDF	Polyvinylidene fluoride

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

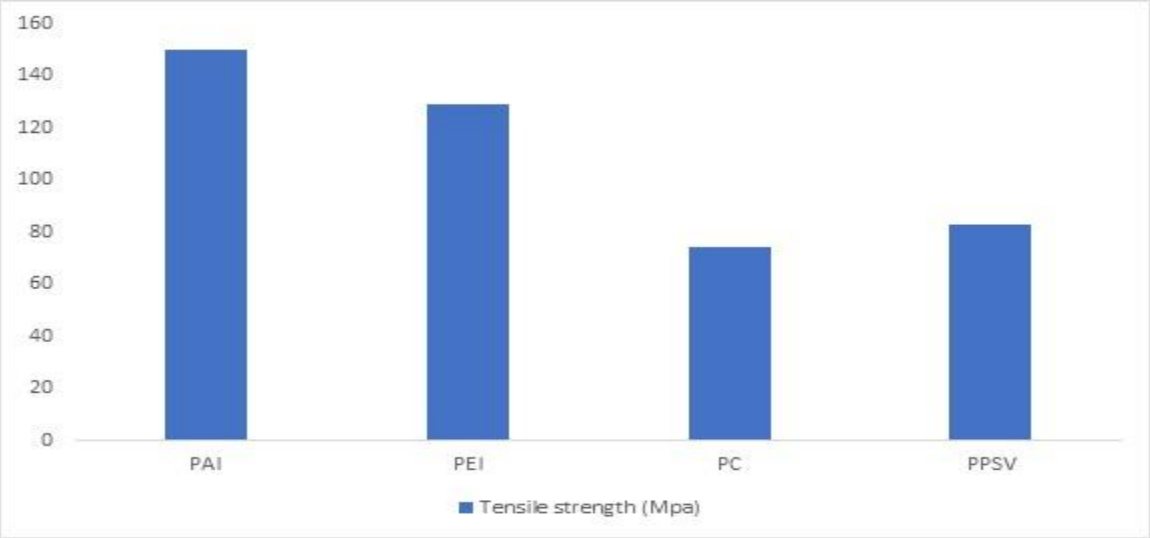

Figure 4: Tensile strength in Mega Pascal of amorphous thermoplastic [54]

Comparison represented above shown that Polyamide-imide(PAI) has maximum tensile strength and Polycarbonate(PC) has minimum tensile strength.[54]

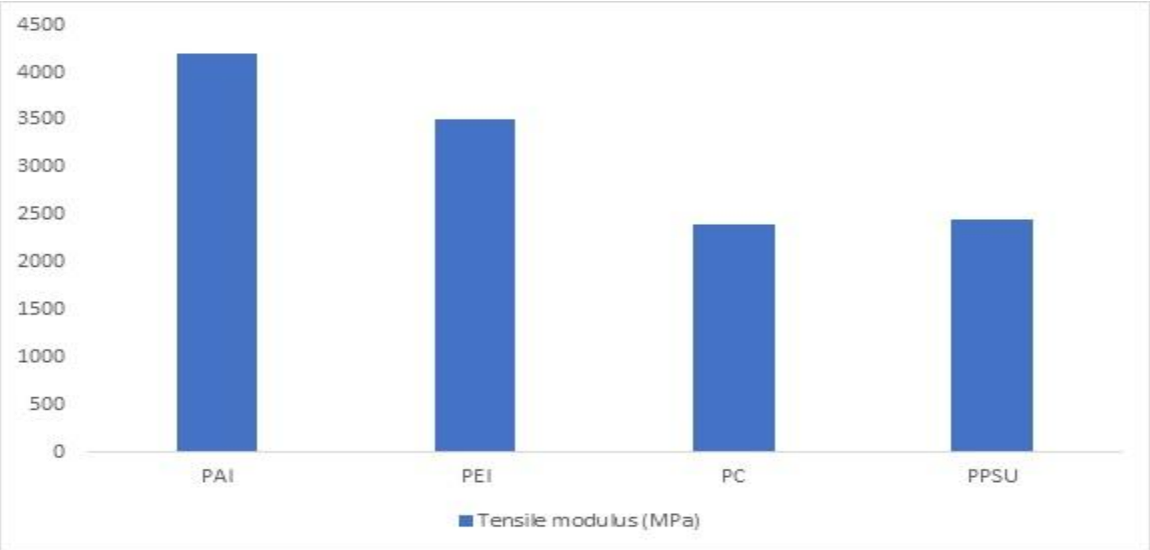

Figure 5: Tensile modulus in Mega Pascal of amorphous thermoplastic [54]

Comparison of tensile modulus shown in Figure 5 represents the similar pattern as of tensile strength that Polyamide-imide (PAI) has maximum tensile modulus and Polycarbonate (PC) has minimum tensile modulus.[54]

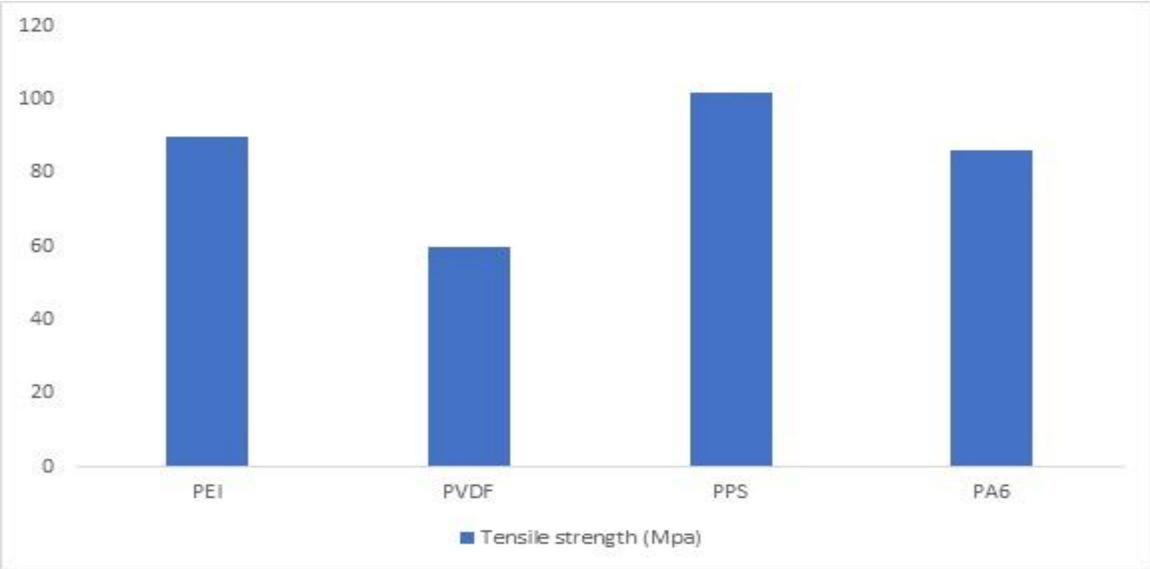

Figure 6: Tensile strength in Mega Pascal of semi-crystalline thermoplastic [54]

Above comparison represents that Polyphenylene sulphide(PPS) shows maximum tensile strength in semi-crystalline thermoplastics, however, Polyvinylidene fluoride(PVDF) shows minimum tensile strength.

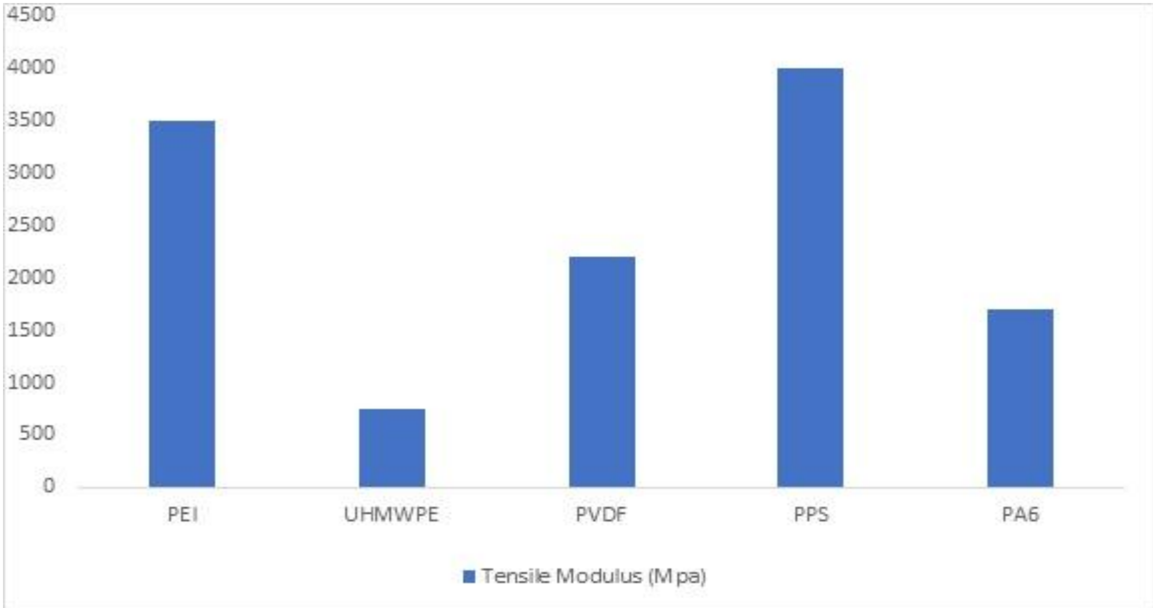

Figure 7: Tensile modulus in Mega Pascal of semi-crystalline thermoplastic [54]

Above comparison signifies that Polyphenylene sulphide (PPS) has maximum tensile modulus, however, Ultra-high molecular weight Polyethylene(UHMWPE) shows minimum tensile modulus in semi-crystalline thermoplastic.

Table 4: Friction and wear rate of different plastics [54]

Materials	PC	PEI	PAI	PPSU	PET	PPS	PA6	UHMWPE	PVDF
Wear rate	2.36E-11	1.79E-11	1.60E-13	2.09E-13	1.22E-13	3.20E-13	8.86E-15	2.53E-14	1.74E-14
Friction/bulk temperature	148	176	171	158	195	227	169	127	155
Wear mechanism	Abrasion	Abrasion	Adhesion-abrasion	Adhesion-abrasion	Adhesion-abrasion	Adhesion-abrasion	Adhesion	Adhesion	Adhesion
Transfer layer characteristics	No Layer	No Layer	Secondary layer	Secondary layer	Secondary layer	Secondary layer	Primary layer	Primary layer	Primary layer

Above table show the wear rate (m^3/mm). Wear mechanism formed into three categories : adhesive, abrasive and adhesive-abrasive wear. For thermoplastic material adhesive wear mechanism used to formed a transferred layer . Primary layer means no addition of material on roughness profile. Secondary layer means poor bonding between the adhesive layer. PC and PEI have higher wear rate with respet to other material.

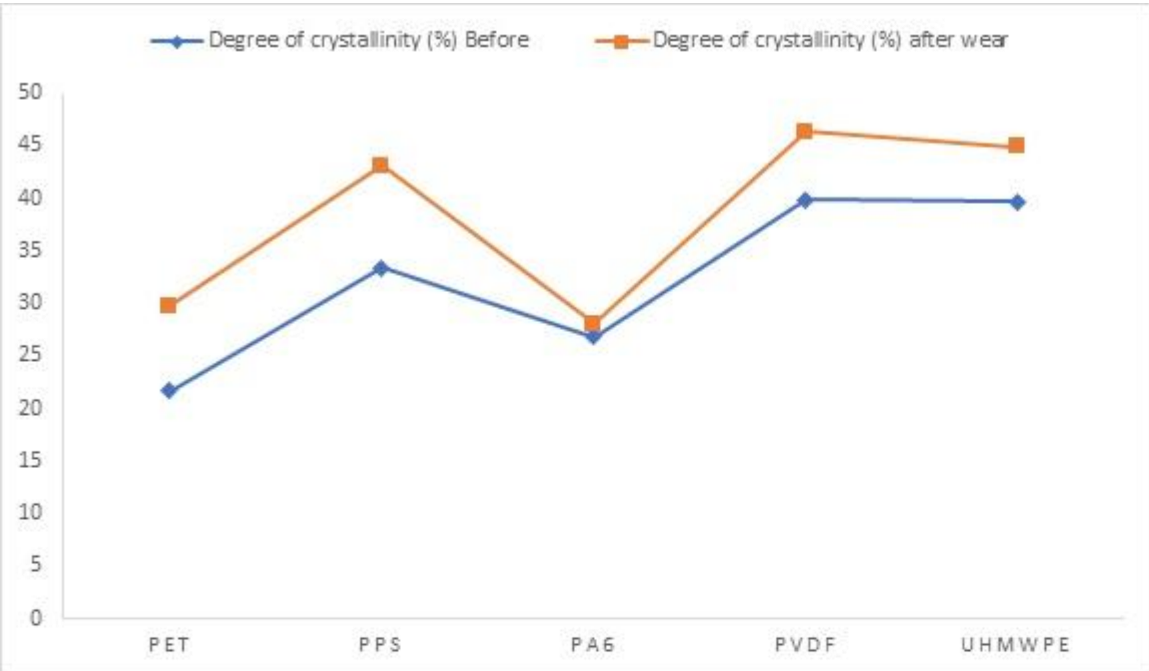

Figure 8: Degree of crystallinity before and after wear test via XRD and DSC

PET and PPS degree of crystallinity improve by 37.5% and 29%. Because of degree of crystallinity hardness increases and plasticity decreased.

Plasma spray method is used for reducing the wear rate. Plasma spray consider un-melted and oxide particles, porosity, different structure and powder form. In this report Al_2O_3 and $ZrO_2$5CaO coating was discussed using plasma spray on pin-on-disc test. Wear rate depends upon the applied load, porosity particles, slops and micro-hardness. The friction coefficient found more due to load effect. Author discussed the friction and wear relationships. Wear rate reduce while increasing the applied load for non-linear depth of hollow. Work hardening also depends upon types of load. At higher load, three bodies abrasion transform into adhesive wear. Friction coefficient found less at 10, 15N with respect to 5N load. Improve the wear

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

rate property with reduction in micro-hardness coating. Al_2O_3 coating has higher micro-hardness as compared to ZrO_25CaO coatings. ZrO_25CaO coating has higher wear loss as compared to Al_2O_3 coating. Wear rate is inversely proportional to hardness and vice-versa. In plasma spray better interfacial bonding found among wear modes and worn material hardness. Wear rate also improved by porosity coating. It may be inter-lamellar porosity. Abrasion rate also depend upon porosity [55].

Semi-metallic material considers metal powder particles such as Cu, Zn and Fe. These metal powder increases the coefficient of friction. The friction coefficient as well as wear properties of brake drum are quite complex and characterized by high pressure,non-steady state and temperature method. In brake rotor cast iron wear resistance is used [56, 57].

Friction Force

MMCs material is used in worldwide due to its tribological properties and mechanical behaviour. According to [58] wear theory, friction force determined by temperature, sliding velocity and power function.

$$F = \mu(T)P^{a(T)}V^{b(T)} \tag{1}$$

F = Force of friction, N

μ(T) = Coefficient of friction at temperature T

P = Load Applied, N

V = Velocity of sliding, m/s

a(T) = Load factor at T

b(T) = Velocity factor at T

At higher velocity of vehicle, frictional force value decreases due to increases in temperature.

Semi-metallic wear coefficient of brake lining material

According to Rhee [59] wear volume depend upon various factors such as sliding time, sliding velocity and power of load function.

$$V = K_f P^a V^b t^c \tag{2}$$

V= wear volume, m^3

K_f= wear coefficient

P= Applied load, N

V= Sliding velocity, m/s

t = Sliding time, second

a, b and c are constant and they depends upon property of material and several condition.

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

Wear Coefficient of MMC disc and Grey Cast Iron

Grey cast iron material is used in automobile applications like brake drum components, disc etc. According to author [60] wear theory, the wear volume determined by hardness, sliding velocity and applied load of the materials.

$$V = \frac{KPL}{3H} \quad (3)$$

V = Material volume, m^3

K = Coefficient of wear

P = Applied load, N

L = Sliding distance, m

H = Hardness

Conclusion

Nowadays wear becomes a major problem in automobile and industries. Owing to wear machine life and machine element damaged after long duration work. Wear rate and wear resistance improved using coating method like thermal spray coating and plasma spray coating. In this paper mechanical and wear properties are discussed:

- Alloy Al7075 has higher toughness and tensile strength value. There is a limitation, has poor resistance.
- 5%TiB_2 has higher wear resistance as compared to 5% SiC with Al6082 alloy.
- 25%SiC. MMCs materials have very high wear resistive properties as matched with grey cast iron
- MMC's materials have 25% higher friction coefficient than grey cast iron.
- Hardness and toughness increased of aluminium metal matrix by addition of material on surface.
- Increased the wear resistance by VN alloy coating on Co-based alloy material.
- The mechanical properties of amorphous and semi-crystallinities thermoplastics under 4MPa pressure and 50mm/s speed shown in figure [4-7].
- PET and PPS materials degree of crystallinity improve by 37.5% and 29%. Because of degree of crystallinity hardness increases and plasticity decreased.
- Al_2O_3 coating has higher micro-hardness as compared to $ZrO_2$5CaO coatings. $ZrO_2$5CaO coating has higher wear loss as compared to Al_2O_3 coating.

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

References

1. Suresh, S., Mortensen, A. and Needleman, A., 1993. Fundamentals of metal matrix composites, published by Butterwor.
2. Deuis, R.I., Subramanian, C. and Yellupb, J.M., 1997. Role of A193 fiber in eutectic Al–Si alloy. *Compos. Sci. Technol*, *57*, pp.415-435.
3. Chattrakul, K. and Sornsuwit, N., 2018. Study of surface appearance and composition effect on AISI 304 and 304L stainless steel wear against nylon wire. *Materials Today: Proceedings*, *5*(3), pp.9319-9325.
4. Shanmugasundaram, A., Arul, S. and Sellamuthu, R., 2018. Investigating the effect of WC on the hardness and wear behaviour of surface modified AA 6063. *Transactions of the Indian Institute of Metals*, *71*(1), pp.117-125.
5. Krishnamurthy, N., Prashanthareddy, M.S., Raju, H.P. and Manohar, H.S., 2012. A study of parameters affecting wear resistance of alumina and yttria stabilized zirconia composite coatings on Al-6061 substrate. *ISRN Ceramics*, *2012*.
6. Tjong, S. C., S. Q. Wu, and H. C. Liao. "Wear behaviour of an Al–12% Si alloy reinforced with a low volume fraction of SiC particles." *Composites Science and Technology* 57.12 (1998): 1551-1558.
7. N. Cincaa, C.R.C. Lima, J.M. Guilemany: J. Mater. Res. Technol. 2(1) (2013) 75-86
8. V. Viswanathan, T.Laha, K.Balani, A.Agarwal, S.Seal: Mater. Sci. Eng. R54 (2006) 121–285
9. Yin, M.G., Cai, Z.B., Li, Z.Y., Zhou, Z.R., Wang, W.J. and He, W.F., 2019. Improving impact wear resistance of Ti-6Al-4V alloy treated by laser shock peening. Transactions of Nonferrous Metals Society of China, 29(7), pp.1439-1448.
10. Axén, N., Jacobson, S. and Hogmark, S., 2001. Friction and wear measurement techniques.
11. Udoye, N.E., Fayomi, O.S.I. and Inegbenebor, A.O., 2019. Assessment of Wear Resistance of Aluminium Alloy in Manufacturing Industry-A Review. *Procedia Manufacturing*, *35*, pp.1383-1386.
12. Kandeva, M., Vasileva, L., Rangelov, R. and Simeonova, S., 2011. Wear-resistance of aluminum matrix microcomposite materials. Tribology in industry, 33(2), pp.57-62.
13. Prasad, K.N.P. and Ramachandra, M., 2018. Determination of Abrasive Wear Behaviour of Al-Fly Ash Metal Matrix Composites Produced by Squeeze Casting. *Materials Today: Proceedings*, *5*(1), pp.2844-2853.
14. Jian, Z., Zhong-yu, P., Shi-ying, L., Sheng-wei, S. and Li-jun, D., 2019. Investigation of wear behavior of graphite coating on aluminum piston skirt of automobile engine. *Engineering Failure Analysis*, *97*, pp.408-415.
15. Sahin, Y., 2003. Wear behaviour of aluminium alloy and its composites reinforced by SiC particles using statistical analysis. *Materials & design*, *24*(2), pp.95-103
16. Cheng, J., Chen, S., Zhang, F., Shen, B., Lu, X. and Pan, J., 2019. Corrosion-and Wear-Resistant Composite Film of Graphene and Mussel Adhesive Proteins on Carbon Steel. *Corrosion Science*, p.108351.

17. Pramod, R., Kumar, G.V., Gouda, P.S. and Mathew, A.T., 2018. A Study on the Al2O3 reinforced Al7075 Metal Matrix Composites Wear behavior using Artificial Neural Networks. *Materials Today: Proceedings*, *5*(5), pp.11376-11385.
18. Krishnamurthy, N., Prashanthareddy, M.S., Raju, H.P. and Manohar, H.S., 2012. A study of parameters affecting wear resistance of alumina and yttria stabilized zirconia composite coatings on Al-6061 substrate. *ISRN Ceramics*, *2012*.
19. Panasuk, A., Umanskyi, A., Storozhenko, M. and Akopyan, V., 2013. Development of TiB2-Based Cermets with Fe-Mo Binder. In *Key Engineering Materials* (Vol. 527, pp. 9-13). Trans Tech Publications.
20. Yung, D.L., Kollo, L., Hussainova, I. and Žikin, A., 2013. Reactive sintering of ZrC-TiC composites. In *Key Engineering Materials* (Vol. 527, pp. 20-25). Trans Tech Publications.
21. Goetsch, T., Neumann, B., Kloetzer, B. and Penner, S., 2019. Substoichiometric zirconia thin films prepared by reactive sputtering of metallic zirconium using a direct current ion beam source. *Surface Science*, *680*, pp.52-60.
22. Skopintsev, V.D. and Vinokurov, E.G., 2019. Tribological Characteristics of Metal-Oxide and Hybrid Composite Coatings. *Glass and Ceramics*, pp.1-5.
23. Bertelli, F., Freitas, E.S., Cheung, N., Arenas, M.A., Conde, A., de Damborenea, J. and Garcia, A., 2017. Microstructure, tensile properties and wear resistance correlations on directionally solidified Al-Sn-(Cu; Si) alloys. *Journal of Alloys and Compounds*, *695*, pp.3621-3631.
24. Del Val, J., Comesaña, R., Lusquiños, F., Boutinguiza, M., Riveiro, A., Quintero, F. and Pou, J., 2010. Laser cladding of Co-based superalloy coatings: Comparative study between Nd: YAG laser and fibre laser. *Surface and Coatings Technology*, *204*(12-13), pp.1957-1961.
25. Lusquiños, F., Comesaña, R., Riveiro, A., Quintero, F. and Pou, J., 2009. Fibre laser micro-cladding of Co-based alloys on stainless steel. *Surface and Coatings Technology*, *203*(14), pp.1933-1940.
26. Farnia, A., Ghaini, F.M., Ocelík, V. and De Hosson, J.T.M., 2013. Microstructural characterization of Co-based coating deposited by low power pulse laser cladding. *Journal of Materials Science*, *48*(6), pp.2714-2723.
27. Yan, H., Zhang, J., Zhang, P., Yu, Z., Li, C., Xu, P. and Lu, Y., 2013. Laser cladding of Co-based alloy/TiC/CaF2 self-lubricating composite coatings on copper for continuous casting mold. *Surface and Coatings Technology*, *232*, pp.362-369.
28. Hua, Z.L.L.L.Z. and Zhengxi, T., 2013. Fatigue Behavior of Graphite/MoS_2 Coatings under Repeated Impact Load. *Lubrication Engineering*, *3*.
29. Hu, T., Zhang, Y. and Hu, L., 2012. Tribological investigation of MoS2 coatings deposited on the laser textured surface. *Wear*, *278*, pp.77-82.
30. Ma, S., Chen, W., Li, C., Jin, M., Huang, R. and Xu, J., 2019. Wear Properties and Scuffing Resistance of the Cr–Al2O3 Coated Piston Rings: The Effect of Convexity Position on Barrel Surface. *Journal of Tribology*, *141*(2), p.021301.

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

31. CHEN, G., HE, Y.H. and SHEN, P.Z., 2009. Research actualities on materials and processes of engine piston parts and cylinder liner [J]. *Materials Science and Engineering of Powder Metallurgy*, *4*.
32. Zhao, B., Dai, X.D., Zhang, Z.N. and Xie, Y.B., 2016. A new numerical method for piston dynamics and lubrication analysis. *Tribology International*, *94*, pp.395-408.
33. Saffari, S. and Akhlaghi, F., 2018. Microstructure and mechanical properties of Al-Mg2Si composite fabricated in-situ by vibrating cooling slope. *Transactions of Nonferrous Metals Society of China*, *28*(4), pp.604-612.
34. Huang, Z.L., Kai, W.A.N.G., Zhang, Z.M., Bo, L.I., Xue, H.S. and Yang, D.Z., 2015. Effects of Mg content on primary Mg2Si phase in hypereutectic Al–Si alloys. *Transactions of Nonferrous Metals Society of China*, *25*(10), pp.3197-3203.
35. Tjong, S.C., Wu, S.Q. and Liao, H.C., 1998. Wear behaviour of an Al–12% Si alloy reinforced with a low volume fraction of SiC particles. *Composites Science and Technology*, *57*(12), pp.1551-1558.
36. Singh, J. and Chauhan, A., 2016. Characterization of hybrid aluminum matrix composites for advanced applications–A review. *Journal of Materials Research and Technology*, *5*(2), pp.159-169.
37. Pramod, R., Kumar, G.V., Gouda, P.S. and Mathew, A.T., 2018. A Study on the Al2O3 reinforced Al7075 Metal Matrix Composites Wear behavior using Artificial Neural Networks. *Materials Today: Proceedings*, *5*(5), pp.11376-11385.
38. Peddavarapu, S. and Bharathi, R.J., 2018. Dry Sliding Wear Behaviour Of AA6082-5% SiC AND AA6082-5% TiB2 Metal Matrix Composites. *Materials Today: Proceedings*, *5*(6), pp.14507-14511.
39. Yung, D.L., Kollo, L., Hussainova, I. and Žikin, A., 2013. Reactive sintering of ZrC-TiC composites. In *Key Engineering Materials* (Vol. 527, pp. 20-25). Trans Tech Publications.
40. Kelly, P.M. and Rose, L.F., 2002. The martensitic transformation in ceramics—its role in transformation toughening. *Progress in materials science*, *47*(5), pp.463-557.
41. Basu, B., 2005. Toughening of yttria-stabilised tetragonal zirconia ceramics. *International Materials Reviews*, *50*(4), pp.239-256.
42. Shanmugasundaram, A., Arul, S. and Sellamuthu, R., 2018. Investigating the effect of WC on the hardness and wear behaviour of surface modified AA 6063. *Transactions of the Indian Institute of Metals*, *71*(1), pp.117-125.
43. Yazdani, B., Xu, F., Ahmad, I., Hou, X., Xia, Y. and Zhu, Y., 2015. Tribological performance of Graphene/Carbon nanotube hybrid reinforced Al 2 O 3 composites. *Scientific reports*, *5*, p.11579.
44. Ocelík, V., Furár, I. and De Hosson, J.T.M., 2010. Microstructure and properties of laser clad coatings studied by orientation imaging microscopy. *ActaMaterialia*, *58*(20), pp.6763-6772.
45. Verdi, D., Garrido, M.A., Múnez, C.J. and Poza, P., 2014. Mechanical properties of Inconel 625 laser cladded coatings: depth sensing indentation analysis. *Materials Science and Engineering: A*, *598*, pp.15-21.

ISSN: 0971-1260
Vol-22-Issue-17-September-2019

46. Wang, D., Hu, Q. and Zeng, X., 2014. Microstructures and performances of Cr13Ni5Si2 based composite coatings deposited by laser cladding and laser-induction hybrid cladding. *Journal of Alloys and Compounds*, *588*, pp.502-508.
47. Amado, J.M., Tobar, M.J., Alvarez, J.C., Lamas, J. and Yáñez, A., 2009. Laser cladding of tungsten carbides (Spherotene®) hardfacing alloys for the mining and mineral industry. *Applied Surface Science*, *255*(10), pp.5553-5556.
48. Huang, Y. and Zeng, X., 2010. Investigation on cracking behavior of Ni-based coating by laser-induction hybrid cladding. *Applied Surface Science*, *256*(20), pp.5985-5992.
49. Ding, L., Hu, S., Quan, X. and Shen, J., 2016. Effect of VN alloy addition on the microstructure and wear resistance of Co-based alloy coatings. *Journal of Alloys and Compounds*, *659*, pp.8-14.
50. Karuppiah, K.K., Bruck, A.L., Sundararajan, S., Wang, J., Lin, Z., Xu, Z.H. and Li, X., 2008. Friction and wear behavior of ultra-high molecular weight polyethylene as a function of polymer crystallinity. *ActaBiomaterialia*, *4*(5), pp.1401-1410.
51. Sperling, L.H., 2005. *Introduction to physical polymer science*. John Wiley & Sons.
52. Stuart, B.H., 1996. Polymer crystallinity studied using Raman spectroscopy. *Vibrational spectroscopy*, *10*(2), pp.79-87.
53. Wright, D.G.M., Dunk, R., Bouvart, D. and Autran, M., 1988. The effect of crystallinity on the properties of injection moulded polypropylene and polyacetal. *Polymer*, *29*(5), pp.793-796.
54. Tóth, L.F., Sukumaran, J., Szebényi, G. and De Baets, P., 2019. Tribo-mechanical interpretation for advanced thermoplastics and the effects of wear-induced crystallization. *Wear*, *440*, p.203083.
55. Krishnamurthy, N., Murali, M.S. and Mukunda, P.G., 2010. Tribological Behavior of Plasma Sprayed Al2O3 and ZrO2 5CaO Coatings on Al-6061 Substrate. *High Temperature Materials and Processes*, *29*(3), pp.111-126.
56. Natarajan, N., Vijayarangan, S. and Rajendran, I., 2006. Wear behaviour of A356/25SiCp aluminium matrix composites sliding against automobile friction material. *Wear*, *261*(7-8), pp.812-822.
57. Cueva, G., Sinatora, A., Guesser, W.L. and Tschiptschin, A.P., 2003. Wear resistance of cast irons used in brake disc rotors. *Wear*, *255*(7-12), pp.1256-1260.
58. Rhee, S.K., 1970. Wear equation for polymers sliding against metal surfaces. *Wear*, *16*(6), pp.431-445.
59. Rhee, S.K., 1974. Friction coefficient of automotive friction materials—its sensitivity to load, speed, and temperature. *SAE Transactions*, pp.1575-1580.
60. Archard, J., 1953. Contact and rubbing of flat surfaces. *Journal of applied physics*, *24*(8), pp.981-988.