Tribological Characteristics of Natural Fiber Reinforced Polyester Hybrid Composites

S.Sathees Kumar

***Abstract**: In order to investigate the wear behavior and tooth damage of Madar and Bauhinia Racemosa fibers reinforced polyester, the composite gears were fabricated with varying the fiber weight percentages of 5%, 10%, 15% and 20%. This paper explores the rolling and sliding of the composite gears running against nylon gear with a simplified method of analyzing and understanding the wear and tooth damage. Tests were conducted without external lubrication over a range of loads 4Nm, 8Nm,12Nm and 16Nm using a gear test rig. The test results of composite gears are compared with unreinforced polyester gear (URPE). It was found that the surface temperature was the primary factor affecting the wear rate and an initial relationship between gear surface temperature and load capacity. This composite can be useful for automobile and industrial applications.*

***Keywords**: Bauhinia Racemosa fiber, gear, Madar fiber, polyester*

I. INTRODUCTION

In recent years, polymeric material gained significant importance in engineering field due to its light weight, environmental resistance and helpful mechanical properties such as specific strength, toughness, and excellent abrasion resistance [1]. The economic and technical advantages of polymer gears have become better appreciated, e.g. an ability to operate without grease or oil lubrication, low cost of production and internal damping capacity and in many of their applications, tooth loading is insignificant [2]. A great number of experimental works involved meshing polymer gears with steel pinions, e.g. nylon against steel [3,4]. Since accurate moulded gears are now available, it is necessary to learn more about the performance of these gears under different operating conditions. The study of moulded gear performance is important for economic reasons because these can be mass produced at a fraction of the cost compared to machined gears. In general, the available information on polymer composite gear wear is still limited and the existing gear surface temperature predictions require further study to be used for practical applications. For instance, Hachman and Strickle's equation [5] was based on the assumption that a lubricant does not contribute significantly to the heat transfer from the tooth. However, this is not the case with gears continuously lubricated with oil [6]. The nylon gear, friction and wear performances are completely different when compared to that of acetal gear.

The different wear and failure behavior when running dissimilar material, especially when acetal as driver against nylon showing better performance [7].

The wear mechanisms of poly-ether-ether-ketone (PEEK) running against itself in non-conformal, unlubricated rolling-sliding contact have been investigated over a range of loads and slip-ratios. The possibility of using PEEK in low slip ratio conditions, for both low and high loads, has been demonstrated with high temperature operation being possible despite an increase of wear[8]. Some research works are reported the mechanical behavior of madar fibers. However, they do give an indication of the high performance of the material. Here, an attempt was made to use the raw fibers, such as, Madar and Bauhinia Racemosa as reinforcement in a polymer matrix. This paper investigate the composite gears running against nylon gear with a simplified method of testing and understanding the wear rate and tooth damage[9].

The wear and weight loss of the composite gears were compared to unreinforced polyester gear. The comparison results of composites have been analyzed and reported. However, tooth damage analysis also carried out to analyze the service life of composite gears. These composite gears can be helpful for an engineering, industries, and automobile applications.

II. MATERIALS AND FABRICATION

Natural fibers used in this work are Madar plant and Bauhinia Racemosa. Bauhinia Racemosa is a small twisted, bushy tree with drooping branches found throughout India. The stem bark was collected from the Kolli Hills. Madar plant does not have any separate stem but branches itself serve the purpose of support and connection with the roots. When grows to its fullest can reach the height of more than 2.5 or 3 meters. Unsaturated polyester resin, accelerator Methyl Ethyl Ketone Peroxide (MEKP) and catalyst Cobalt Naphthalene were purchased from Kovai Seenu Fabrics Ltd, Coimbatore.

Design of gears

Composite gear (glass fiber reinforced nylon with PTFE as internal lubricant) and acetal gears are manufactured and relationship is built between wear rate and surface temperature [10].

Manuscript published on 30 August 2019.
*Correspondence Author(s)
Dr.S.Sathees Kumar, Professor, Department of Mechanical Engineering, CMR Institute of Technology, Hyderabad.

Gear temperature was analyzed in three components: ambient, bulk and flash temperatures. From that the surface temperature is the foremost factor influencing the wear rate [7].

After some experimental research, it was found that composite gears failed by root and pitch fractures. In order to improve the natural fiber composites, the polymer gears are reinforced with madar and Bauhinia Racemosa fibers and tested its performance as mentioned in the literatures. The designation and volume fraction of reinforced and unreinforced composite gears are shown in Table.1. Fabricated Madar and bauhinia racemosa fiber composite gears are shown in Fig.1. The composite gears are fabricated by gear hobbing machine [11].

Table.2 Designation and volume fraction of reinforced and unreinforced composite gears

Name of gear	Designation of gears	Volume fraction of Fiber (%)	Volume fraction of Polyester (%)
Madar Fiber gears	MG1	5	95
	MG2	10	90
	MG3	15	85
	MG4	20	80
Bauhinia Racemosa Fiber gears	BRG1	5	95
	BRG2	10	90
	BRG3	15	85
	BRG4	20	80
Unreinforced Polyester	URPE-G	---	100

Fig.1 Madar and Bauhinia Racemosa composite gears

III. DETERMINATION OF WEAR DEPTH MEASUREMENT

Mao et al. measured the wear depth of the acetal and nylon gears in terms of tooth reduction. The gear tooth vernier is used to measure the tooth thickness of the gear teeth at the pitch line, with 0.02 mm accuracy. It has two scales: vertical and horizontal. Vertical scale ranges from 0 to 40 mm and the horizontal scale ranges from 0 to 20 mm. Both the scales are set for the tooth. One is for the width / thickness (W) of the tooth and another one is for the depth (d) from the top of the tooth(c), where (W) occurs. Theoretical thickness / width was calculated using the Equation (1).

$$W = Z \times m \times \sin(90/Z) \quad --- \quad (1)$$

The theoretical thickness value (W_{the}) was set in horizontal vernier scale and corresponding depth (d) was noted for the fresh gear. The same depth (d) was set as constant for measuring corresponding actual thickness (W_{act}) value for further investigation. At every interval of 0.20×10^6 cycles the experiment was stopped, to measure the gear tooth thickness by gear tooth Vernier. To take the tooth thickness, least count of 0.2 mm was multiplied with Vernier scale reading and summed up with main scale reading to get the actual thickness (Wact) of the tooth. Measurements were taken on the same three teeth on each gear and their average was calculated. For the fresh gear the chordal thickness is 3.14 mm

IV. RESULTS AND DISCUSSION

Effect of Wear depth at 4 Nm

From the wear test, it is observed that URPE-G gear exhibited more wear rate compared to others. For URPE-G, rapid wear depth of 0.07 mm reached after completing 0.80×10^6 cycles. It shows that local melting in the material occurred due to rise in temperature. Severe wear and tooth damage were recorded at 1.20×10^6 cycles. The wear rate of URPE-G and composite gears under load of 4Nm are shown in Fig.2.

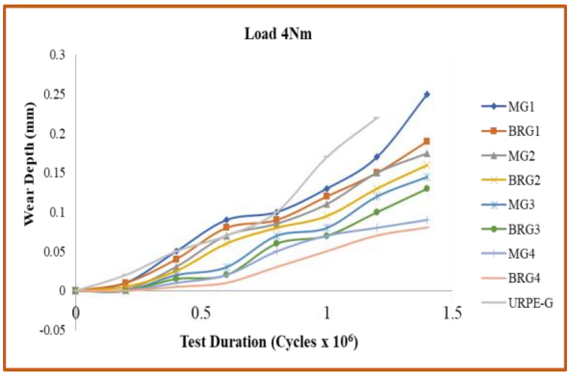

Fig.2. Wear rate for URPE-G and composite gears under load of 4 Nm

Similar trend of wear curve was observed for MG1 and BRG1 gears up to 1.20×10^6 cycles, with a difference in wear rate of 0.01 to 0.02 mm. At 1.40×10^6 cycles, sudden increase in wear of 0.06 mm was observed for MG1 gear, compared to BRG1. It was noted that small wear fragments occurred in MG1 and BRG1 gear due to increase in temperature and it is shown in Fig.3.Similar trend of wear curve was observed for MG1 and BRG1 gears up to 1.20×10^6 cycles, with a difference in wear rate of 0.01 to 0.02 mm. At 1.40×10^6 cycles, sudden increase in wear of 0.06 mm was observed for MG1 gear, compared to BRG1. It was noted that small wear fragments occurred in MG1 and BRG1 gear due to increase

in temperature and it is shown in Fig.3 (a and b).

Retrieval Number: J90930881019/19©BEIESP
DOI: 10.35940/ijitee.J9093.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Also, similar trend of wear curve was observed in MG2, BRG2, MG3 and BRG3 gears. MG2 and MG3 gears showed increase in wear rate within a range of 0.01 - 0.03 mm, compared to BRG2 and BRG3 gears. Tooth wear was observed more in MG2 and BRG2 gears due to softening of the material. Tooth damages of MG2 and BRG2 are shown in Fig.3 (c and d) and pitch line wear of MG3 and BRG3 gears are shown in Fig.3 (e and f).

With regard to MG4 and BRG4 gears, no wear was observed up to x 10^6 cycles. After this, constant wear depth of 0.01 mm was observed up to 0.60 x 10^6 cycles. Wear depth of 0.02 mm increased for MG4 gears compared to BRG4. This might be recognized to the fact that the strength of the adhesive bond formed between the resin and fibers in BRG4 gears is more than MG4 gears. A segment of gear is ready to fall from MG4 gear, and pitch line wear of BRG4 gear are shown in Fig. 3 (g and h).

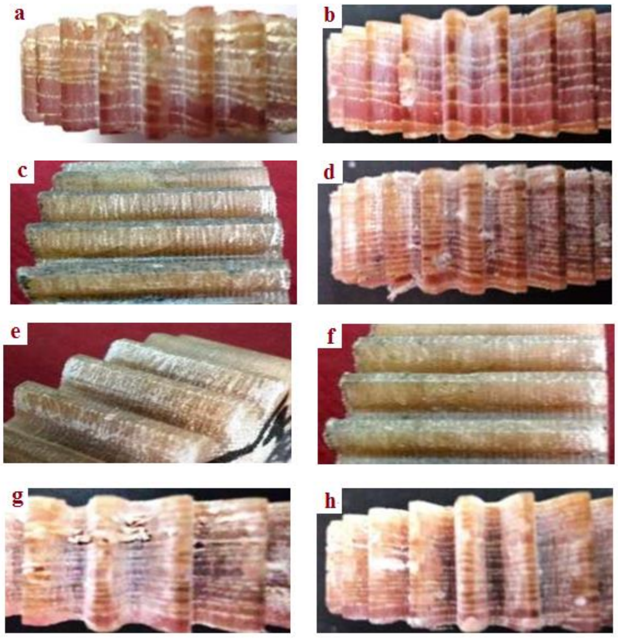

Fig.3. Wear forms on gear tooth under load of 4 Nm with different V_f %
(a) MG1 (b) BRG1 - 5% , (c) MG2 (d) BRG2 - 10% , (e) MG3 (f) BRG3 - 15% and (g) MG4 (h) BRG4 - 20%

Effect of wear depth at 8 Nm

From the test results, wear rate of unreinforced gear suddenly increased up to 0.21 mm within a short interval due to increase in load. Material melt occurred around the pitch line region of URPE-G gear and severe damages of gear tooth were observed.

Wear depth of 0.43 mm was recorded at the time of tooth breakage. The wear rate of URPE and composite gears under load of 8Nm are shown in Fig.4.

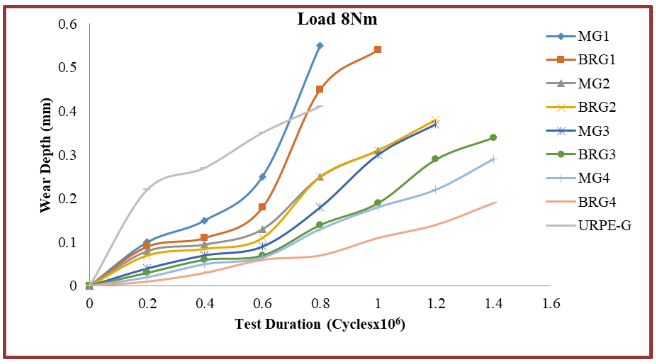

Fig.4. Wear rate for URPE-G and composite gears under load of 8 Nm

With regard to the reinforced gears, MG1 and MG2 showed more wear rate after 0.60 x10^6 cycles and its wear depth exceeded more than mm in comparison with URPE-G. This is because, under continuous running, gear material becomes worn out and reinforced material comes in contact with the mating gear, which roughens the test gear surface and finally wear debris are formed. Tooth damages of MG1 and BRG1 gears are shown in Fig.5 (a and b).

BRG1, BRG2 and MG3 gears showed a similar trend of wear curves within the range of 0.05 – 0.07 mm. BRG2 and MG2 gear tooth damages are shown in Fig .5 (b and c). Minor wear damages of tooth surface were observed for BRG3 and MG4 gears. BRG3 and MG3 gear damages are shown in the Fig.5 (c and d). When compared to BRG3 and MG4 gears, BRG4 gear caused less change in tooth thickness.

Sudden change of tooth thickness occurred in BRG3 and MG4 gears between 0.80 x 10^6 and 1.20 x 10^6 cycles, in comparison with BRG4 gear. This is due to increase in tooth surface temperature of gears, which caused reduction in tooth thickness. Gear damages of MG4 and BRG4 are shown in Fig.5 (e and f).

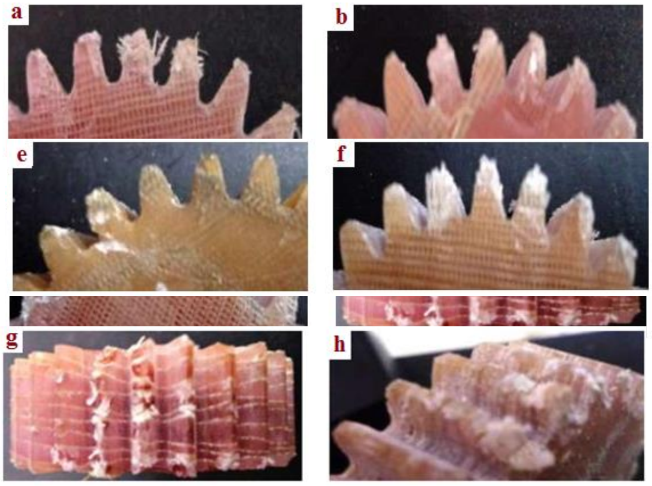

Fig.5 Wear forms on gear tooth under load of 8 Nm with different Vf %
(a) MG1 (b) BRG1 - 5% , (c) MG2 (d) BRG2 - 10% , (e) MG3 (f) BRG3 - 15% and (g) MG4 (h) BRG4 - 20%

Retrieval Number: J90930881019/19©BEIESP
DOI: 10.35940/ijitee.J9093.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Effect of wear depth at 12 Nm

Wear depth steeply improved with time for URPE-G and MG1 gears up to 0.40 x 10^6 cycles, in relationship with other reinforced gears. It was clearly exposed that the wear depth of these gears is reasonably higher due to increase in load which leads to increase in temperature. With the increasing temperature in this region, the mechanical properties of these gears reduced. Especially under great torque levels, the service life of these gears shortened. The wear rate of URPE and composite gears under load of 12Nm are shown in Fig.6.

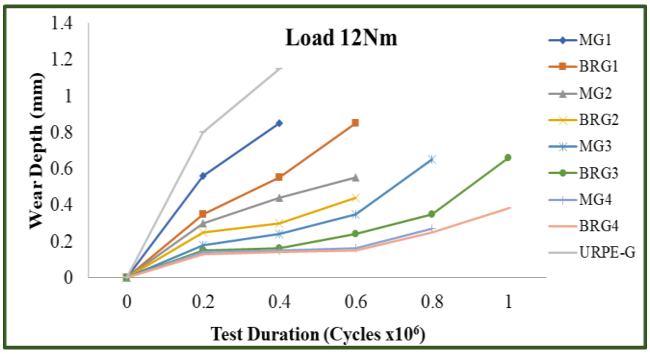

Fig.6. Wear rate for URPE-G and composite gears under load of 12 Nm

Fig .7 displays the damaged gears of MG1 and BRG1. BRG1, MG2 and BRG2 gears which run up to 0.60 x 10^6 cycles. Gear tooth root cracking and tooth wear were witnessed in these gears after 0.20 x 10^6 cycles as shown in Fig.7 (a and b). However, outside this limit a significant plastic deformation of gear tooth was detected and finally gear tooth breakage happened. A similar observation was noted for MG3 and MG4 gears. Fig.7 (c and d) shows the worn out teeth of MG2 and BRG2 gears.

Fig.7 (e and f) shows the teeth damages of MG3 and BRG3 gears. In the case of BRG3 and BRG4 gears, sensible wear depth was found. However, at x 10^6 cycles, BRG3 gear showed greater wear difference of 0.29 mm than BRG4 gear due to escalation in load and temperature. MG4 and BRG4 gear tooth damages are shown in Fig.7(g and h)

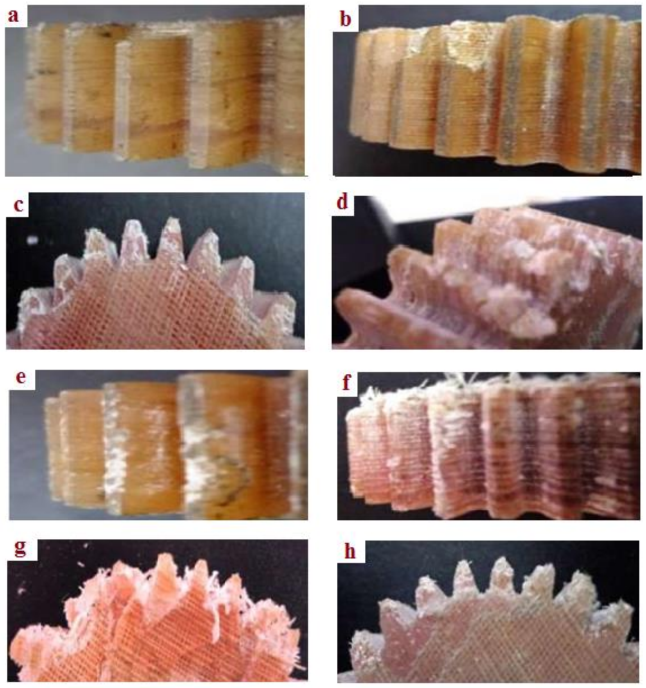

Fig.7.Wear forms on gear tooth under load of 12 Nm with different Vf %
(a) MG1 (b) BRG1 - 5% , (c) MG2 (d) BRG2 - 10% , (e) MG3 (f) BRG3 - 15% and (g) MG4 (h) BRG4 - 20%

Effect of wear depth at 16 Nm

From the result, it is noted that substantial wear rate increased at greater torque levels and reduced thermal conductivity of the URPE-G gear led to severe temperature induced plastic deformation. A steep growth in wear depth was found in MG1 and BRG1 gears, and similar type of material distortion was observed, as URPE-G. The wear rate of URPE and composite gears under load of 16Nm are shown in Fig.8.

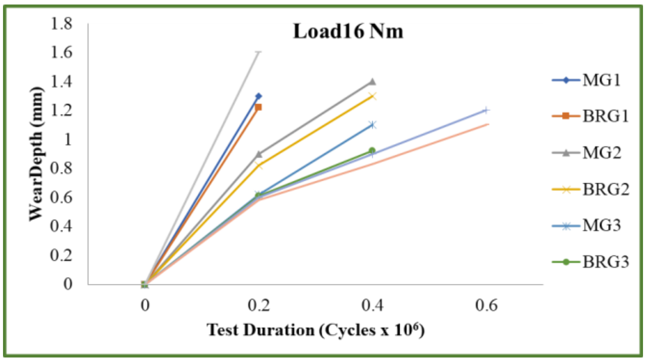

Fig.8. Wear rate for URPE-G and composite gears under load of 16 Nm

Retrieval Number: J90930881019/19©BEIESP
DOI: 10.35940/ijitee.J9093.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Fig.9. (a and b) shows the absolutely damaged MG1 and BRG1 gear tooth. Both unreinforced and reinforced gears demonstrated more wear depth when associated to previous loads. The surface temperature and the thermal stability of the material expressively affected the wear phenomena in polymeric materials. The polymeric material surface softened at high temperatures and led to severe wear. The low thermal stability of MG1, BRG1, MG2 and BRG2 gears ensued in high wear rate. Therefore at high torque levels, gear tooth bend was severe due to the poor mechanical properties and the teeth engagement at the following tooth took place more forcefully. It changed the gear action and initiated severe wear on the gear tooth surface. Fig.9 (c and d) shows the tooth damages of MG2 and BRG2 gears. Fig 9.(e and f) shows the gear tooth damages of MG3 and BRG3 gears. However for MG4 and BRG4 gears due to enhanced mechanical properties of materials compact wear depth was observed. The worn out teeth of MG4 and BRG4 gears are shown in Fig.9(g and h).

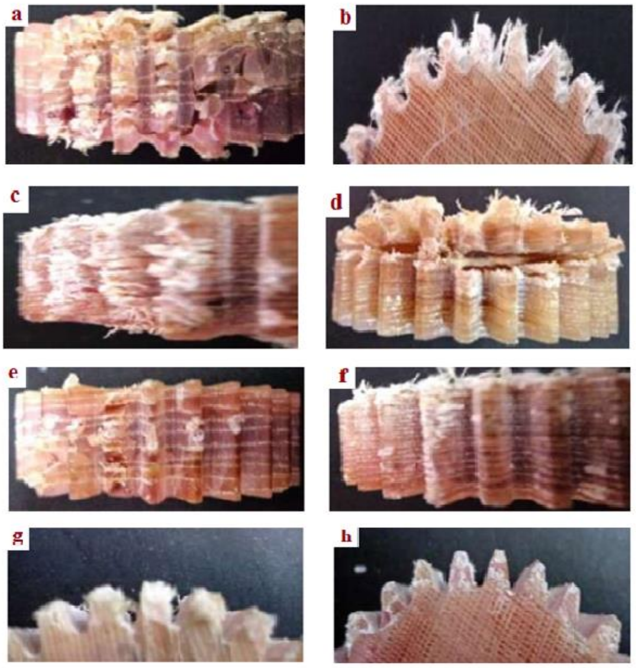

Fig.9.Wear forms on gear tooth under load of 16 Nm with different Vf %
(a) MG1 (b) BRG1 - 5% , (c) MG2 (d) BRG2 - 10% , (e) MG3 (f) BRG3 - 15% and (g) MG4 (h) BRG4 - 20%

The average wear depth results of all gears at various torque levels. From these results, it is concluded that URPE-G gear showed significant wear depth followed by MG1 and BRG1 gears. Related trend of wear depth was detected in MG2 and BRG2 gears at 16 Nm torque level. MG3, BRG3, MG4 and BRG4 gears demonstrated better wear resistance up to 12 Nm torque level. However, it should be renowned that Bauhinia Racemosa fiber mat reinforced polymer gears performed well associated to madar fiber mat reinforced polymer gears.

V. CONCLUSION

- Natural fibers were extracted from the Madar and Bauhinia Racemosa fibers and the composites gears were fabricated by gear hobbing method. Tribological and tooth damage analysis also carried out.
- High wear depth was recorded in URPE-G and MG1 gears, while low wear depth was observed in MG4 and BRG4 gears. It was clear that higher volume fraction gears showed less wear rate.
- MG4 and BRG4 gears recorded surface wear up to 0.60 x 10^6 cycles. It was observed that increasing the torque range results in severe plastic deformation on the gear tooth surface.
- From the conclusions, the wear depths of unreinforced and reinforced gears were higher at operating torques of 12N-m and 16N-m. Even 20% volume fraction gears faced severe tooth damages after completing 0.20 x 10^6 cycles.
- This type of composite materials can be useful for automobile and industrial applications.

REFERENCES

1. Wang Y , Chen KS, Mishler J, Cho SC, Adroher XC, Appl. Energy , Vol 88, pp 981–1007, 2011.
2. Li W, Wood A, Weidig R, Mao K, “An investigation on the wear behaviour of dissimilar polymer gear engagements”. Wear , Vol 271,pp2176-2183,2011.
3. Gauvin R, Yelle H, Safah F, “Experimental investigation of the load cycle in a plastic gear mesh, in: International Symposium On Gearing and Power Transmission, Tokyo, pp473–478 , 1981
4. Tsukamoto N, “Investigation about load capacity of nylon gears”, Bulletin of JSME 27 Vol 229, 1984.
5. Hachman H,Strickle E, “Nylon gears”, Konstruktion, Vol 3, Issue 18, pp81–94, 1966.
6. Chen JH, Juarbe FM, “How lubrication affects MoS2 filled nylon gears”, Power Transmission Design, pp34–40 1982..
7. Mao K, Li W, Hooke CJ, Walton D , “Friction and wear behaviour of acetal and nylon gears”, Wear, Vol 267 pp639–645, 2009.
8. Hoskins TJ , Dearn KD , Chen YK, Kukureka SN,”The wear of PEEK in rolling–sliding contact – Simulation of polymer gear applications” , Wear , Vol 309,pp35–42. 2014.
9. Senthilvelan S, Gnanamoorthy, “Damage mechanisms in injection molded unreinforced, glass and carbon reinforced nylon 66 spur gears”, Applied Composite Materials, Vol 11, pp337- 397, 2004.
10. K. Mao, A new approach for polymer composite gear design, Wear 262 (2007) 432-441.
11. Sathees Kumar S, Kanagaraj G, “Evaluation of mechanical properties and characterization of SiC reinforced PA6 polymer composites and its engineering applications”, International Journal of Polymer Analysis and Characterization. Vol 21,Issue 5, pp378-386, 2016.

AUTHORS PROFILE

Dr.S.Sathees Kumar completed his doctoral work in the area of polymer composites from Anna University, Chennai in 2017. He obtained his PG degree in M.E (CAD/CAM) from Anna University, Chennai in 2008 and UG degree in Mechanical Engineering from Anna University, Chennai in 2005. He is having more than 12 years of teaching experience and served in various esteemed Engineering colleges. He is currently working as a Professor of Mechanical Engineering Department in CMR Institute of Technology, Hyderabad, Telangana, India. His main research interests are: polymer composites, material science, material characterization and natural fiber composites. He has 09 (3 – Springer, 1 Taylor & Francis, 1 De-Gruyter and 4 Scopus) publications in reputed international journals. He has attended various National and International Conferences, Workshops, Short Term Training Programmes in reputed Engineering colleges. He is having Lifetime Membership in Institute of Engineers (IE)

Retrieval Number: J90930881019/19©BEIESP
DOI: 10.35940/ijitee.J9093.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)