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Applicability of Composite Polymer Gear in Low RPM Applications – A Review

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ABSTRACT : *Composite polymer gears are being used in many engineering applications because of their low weight, low cost, self-lubrication capability and mass manufacturing possibility. With the continuous evolvement of science and technology the use of polymer gears is increasing in all the upcoming industries. Because of this advancement, this polymer gear's failure can cause the catastrophic collapse for the machine. That is why the gear stress analysis, the transmission errors, the prediction of gear dynamic loads, gear noise and the optimal design for gear sets are always major concerns in gear design. This paper reviews how composite polymer gears perform under various load applications. Different reinforcements with composite polymer improved fiber interface bonding and increased strength of the composites. The negative impacts of fiber's physical treatments on tensile and impact properties of polymer gears were also reviewed.*

KEYWORDS *-Plastic gear, Failure modes, Wear, Composite Materials*

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I. Introduction

Gears are key element to majority of mechanical machinery. Gears are the most common means of transmitting power in mechanical engineering. With the continuous evolvement of science and technology the use of gears has become more common in all the upcoming industries. That is why their failure can cause the catastrophic failure of those machines. That is the main reason for failure analysis and sustainable life of gear with optimum cost and design. Optimum design helps keeping safety while operating the machine by preventing injuries due to failure.

Therefore, it is most important to correctly dimension the gear for one specific function. This task has been difficult due to the complexity of meshing phenomenon associated with the gears. Also, the gear material-specific properties and applications which decides its critical failure and the maintenance goals. By doing this, the total ownership cost in its lifetime and the safety of the system is increased. The study of moulded gear performance is important as these are easy to mass manufacture as compared to machined gears which makes them more economical.

The difference between plastic and metallic gear behaviour occurs because plastic gears have an elastic modulus around hundred times lesser than that of steel and thirty times of aluminium. The heat is generated during meshing by friction, bending hysteresis which takes place at the surface of the teeth. One of the main cause of failure in plastic gears is temperature because of the very low melting point of polymer material.

The industry appreciates the technical and economic advantages of polymer gears. The reason for the success of Polymer Gears is their low cost (mass production), low weight, high resilience, internal damping capacity, noiseless operation and ability to operate without any lubrication. The use of polymer gears is increasing in various industries. Plastic gears are used in automotive industry, office machine, household utensils, and food and textile machinery. Office machines include the Xerox machines, printers and ATMs. Household Applications have mixers, grinders and food processors. These applications are the reason of no lubrication need in polymer gears.

II. Literature Review

The gear stress analysis, the transmission errors, and the prediction of gear dynamic loads, gear noise, and the optimal design for gear sets are always major concerns in gear design. When the load reaches a critical value for a specific geometry, the polymer gear rate increases. This wear rate can be slowed down only if the gearsare loaded below critical load. One of the possible reason for this increment in rate of wear is the gear operating temperature which reaches material melting point under critical condition load.

1.1 Design Procedure

Mao [1] proposed a design method which was based on the link between wear rate of polymer gear and its surface temperature. He found out that the polymer gear wear was increased when for a specific geometry load reached a critical value. The gear surface wear was slow in the case of load below critical. The reason for this immediate increase in gear wear rate was because of the gear operating temperature reaching the material melting point under condition of critical load.

Aljaz and Joze [2] presented a new accelerated testing procedure. It was to be used for Polymer Gears based on several different levels of testing. This method was applied on a pair of gears. To test these materials different speeds of rotation, torque loads and transferred powers were used. It was concluded that Polymer gears failed in 2 methods: Fatigue and Melting of gear tooth. By using Life span tests, fatigue can be measured. Melting of gears is consequence of increase in temperature and overload.

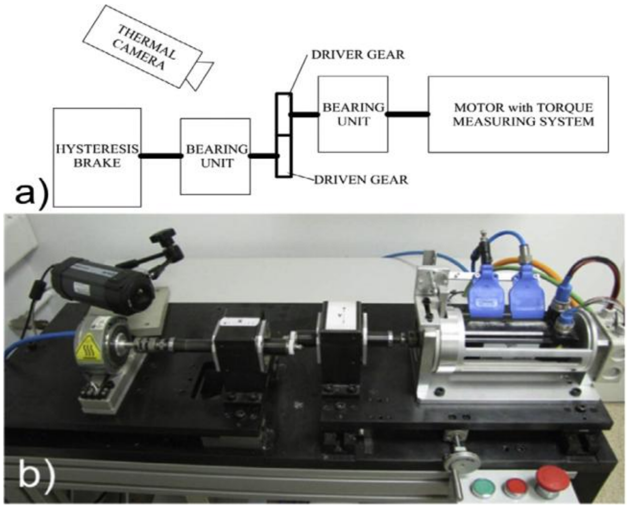

Fig 1. (a) Schematic and (b) picture of the polymer gear test rig. [2]

B. Trobentar et al. [3] has mathematically studied the behaviour of spur polymer gear using the Young's material model and hyper elastic Marlow model which are then compared with the VDI 2736 standard. Finally, it was concluded that instead of using the standardized procedure for the gear tooth deflection, when linear elastic or hyper elastic model is used the deflection observed is less.

Eric Letzelter et al. [4] proposed a new experimental method to measure the thermal behaviour of polymer gears. The polymer gears were made of Nylon 6/6 material. They performed thermal measurements on the gear teeth profile. It was concluded that heating is homogeneous. The main 3 sources for heating were found as: Friction, heating of rotating shaft and trapping between the teeth. And later it was found out that under load conditions, friction could not be neglected.

1.2 Materials

Common materials which are being used in composite polymer gears are polyoxymethylene (POM), polyamide (PA), polypropylene (PP), nylon 66, etc. With these materials, reinforcements like carbon fiber, glass fiber and metal fibers are used. And sometimes lubrication films of molybdenum disulphide, boron nitride, graphite flakes and poly tetra fluoro ethylene (PTFE) are used to strengthen the base material.

K. Mao et al. [5] used acetal and nylon gears in all possible combinations as acetal-acetal, acetal-nylon, nylon-acetal and acetal-acetal as driver-driven. He concluded that in the case of acetal-acetal gear arrangement the wear rate increased after a certain value of load for a specific geometry. It then confirmed that the wear rate

increased with increase in tooth surface temperature. Then after it was concluded that when acetal was used as driver gear and that nylon as driven gear the wear rate was the least as compared to the other combination.

S. Senthivelan and R. Gnanamoorthy [6] studied the behaviour of an unreinforced nylon 6/6 gear with a 20% short glass fibre reinforced nylon 6/6. The gears are injection moulded and the effect of fibre orientation is studied under optical microscope. Computer aided stimulation is carried out and the result is given after experimentally testing the prepared sample of gears.

Restricted shrinkage results in less gear profile deviation of the reinforced gear than the unreinforced one. Deviation in the involute profile is observed more in the gears with low surface smoothness i.e. the reinforced gears which contain hard fibres.

T.J. Hoskins et al. [7] tried combinations of Polyoxymethylene (POM), Unreinforced Polyether-Ether-Ketone (PEEK), Carbon Fibre reinforced PEEK, Polyamide 6/6, Glass Fibre Reinforced Polyamide 6/6 materials. It was concluded that Surface roughness of Polyoxymethylene is inversely proportional to speed. But in the other materials tested is proportional to both load and speed. The sound power level of Polyoxymethylene is inversely proportional to speed but proportional to load. But in other material tested is proportional to both load and speed.

S Senthivelan and R Gnanamoorthy [8] used a power absorption type gear test rig and selected injection moulded unreinforced and 20% short glass fibre reinforced Nylon 6 spur gears to study their effect on variable rotation speeds and torques. It was then concluded that due to more thermal deformation resistance and higher mechanical strength, reinforced nylon 6 with 20% short glass fibre performed exceptionally good. Gear wear and cracking at tooth roots led to failure whereas no effect of gear speed played any role in reducing the gear life at lower stresses. At higher stresses it was observed that increase in the rotational speeds increased the gear's surface temperature which in turn led to the failure and reduced the gear life.

S Senthivelan & Gnanamoorthy [9] observed the effect of tooth fillet radius on the performance of gears. Two injection moulded nylon 6/6 gears with fillet radii of 0.25 and 0.75 mm were selected, it was concluded that the temperature rise is dependent on the fillet radius. From the power absorption gear test rig, it was conformed that the gear with the smaller fillet radius failed due to the increase in stress concentration at the roots which led to crack formation whereas micro cracking at the pitch was the reason of failure of the larger fillet radius gear.

W. Li et al. [10] presented an extensive investigation which was based on wear and friction behaviour of dissimilar polymer gear contact. The observations taken on the pair of acetal gears against nylon gears. When acetal gear was driver, wear rate found was low. They also took observations on the combinations of pair of PEEK and steel. Their conclusion was that acetal gear as driver against nylon gear shows best performance compared with other combinations. The reason for this performance was due to wear rate of root being much lower than that in the tip.

J. Cathelin and A. Sedighiamiri [11] conducted an experimental and a numerical study on the thermal aspects of a loaded 30% glass fibre reinforced polyamide 6 gear which is injection moulded. Their numerical study was based on 3 steps: real tooth geometry definition, kinematics solution and calculations under load. After this experimental validation were carried out on a test rig and a better correlation while implementing the tooth profile correction according to the measurement on moulded gear was obtained.

Johnney Merterns A and Senthivelan S [12] studied the effect on the surface temperature of a mating metal-polymer gear. Injection moulded polypropylene gears were taken and observed by a 3D non-contact profiler that larger bearing area was due to higher surface roughness and that the steel gear with the higher order of roughness generated the more heat at the contact. Also, bearing area and surface friction increased with increasing load.

K. Mao et al. [24] also found that acetal material gear performance was completely based on temperature of the surface. Sudden increase in wear rates was found as transmitted torque was increased to the critical value. It is because of the polymer material gear surface temperature was at its melting point. Further investigation on the same material was carried out and flash and bulk temperatures of material were predicted.

Hayrettin Duzcukoglu [25] modified the gear tooth. He drilled holes in the gear teeth in order to distribute the surface temperature. The conclusion of this method was that these holes acted as cooling holes. And decreased the tooth surface temperature. It also increased load carrying capacity of the gear and wear resistance of gear which increased the gear life and decreased the surface temperature.

T.J. Hoskins et al. [26] studied the wear behaviour of two poly-ether-ether-ketone (PEEK) discs. Investigation was carried out without any lubrication for a range of slip ratios and loads. They used a twin-disc test rig.

P.K. Singh and A.K. Singh [13] investigated three different materials which were Acrylonitrile Butadiene Styrene (ABS), High Density Polyethylene (HDPE) and Polyoxymethylene (POM). The gears were injectionmoulded. Different torques of 0.8, 1.2, 1.6 and 2.0 Nm along with rotational speeds of 600, 800, 1000 and 1200 rpm were tested on these three material gears.

Fig 2. Injection moulded gears [13]

The strain rate affects the mechanical properties of polymer. As the strain rate increases, the polymer improves hardness and strength. This increases the material wear strength [14]. An increase in rotational speed expands the strain rate that causes decrease in polymer tooth wear rate. For all the torque levels, the ABS have maximum wear rate followed by HDPE and POM material polymer gears. At these conditions, durability of ABS, HDPE and POM material gears is found to be 0.5, 1.1, 2.0 million cycle revolutions.

1.3 Manufacturing Process

Polymer gears are produced by different methods which are injection moulding, compression moulding and wire-cut electric discharge machining process. These are all the traditional methods to produce any polymer product. Recently plastic gears are being manufactured with additive manufacturing process. A CAD model is designed on any of the CAD software and then it is sent to the additive manufacturing printer (3d printer), where the design is turned into product with layer by layer de-positioning which is known as additive manufacturing or rapid prototyping or 3D printing.

1.4 Gear Damage Modes

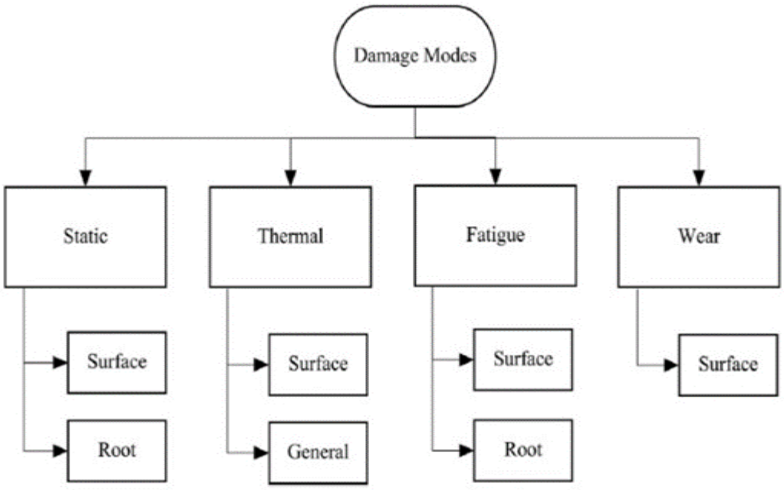

Fig 3. Damage modes present in plastic gears [14]

Deformations: Because of excessive surface stress at area of contact, involute profile of gear is permanently distorted [15].
Surface thermal failure: Because of excessive heat, the tooth softens resulting in melting of the material and decays [20], [22], [23].
Root fatigue: Stress concentration in teeth roots starts microcracking which propagates and causes the failure in gear reducing the gear life [16].
Wear: Combination of applied force and speed of sliding causes the material removal on tooth surface [17]-[19].
Thermal failure: Under the effects of heat hysteresis and friction, polymer material loses its mechanical properties which causes the tooth pf polymer material to soften [5], [20], [21].

Table I. Commonly used Materials for Polymer Gear and their properties:

Material	Specific Gravity	Impact Strength (Izod) (J/m)	Tensile Strength (MPa)	Tensile Elongation (%)	Tensile modulus (MPa)	Flexural Strength (MPa)	Injection Pressure (MPa)	Melt Temperature (C)
PEEK	1.30	53	93	>10	3792	145	83-124	349-399
Nylon 6/6 (PTFE induced)	1.17	53	76	>10	3103	107	69-124	277-299
PMMA	1.18	21	65	3.5-5.5	3448	90	69-103	182-218
Nylon 6/6 (PA) Glass Fibre (13%) Heat Stabilized	1.23	5 kJ/m2	120	3.5	5700	180	70-125	275-300
HDPE	0.98	112	28	>10	1862	29	69-103	193-232
POM	1.41	80	60	>10	2413	76	69-103	182-218
PTFE	2.18	---	35.85	3.6		8.44		
Nylon 6 (PA)	1.23		103	3.0-4.0	6500	165	70-105	245-280

Glass Fibre (15%) Heat Stabilized								
PP	0.91	53	32	>10	1724	41	69-103	191-232

III. Conclusion

In the above studies, it was observed that weight reduction has a role to perform in the coming years. Research is carried out to maximize the performance of the gears and optimizing the weight and strength of the gears. Due to this need, polymer composite gears were introduced. There is a scope to polymer composite gears. The materials that are presently being used are Nylon, Polyoxymethylene (POM), Polylactic acid (PLA), Acrylonitrile Butadiene Styrene (ABS) and High-Density Polyethylene (HDPE) with the reinforcements of glass fibre and carbon fibre. With the present research done in the field, it’s concluded that the tooth surface temperature rises the most in the case of POM and lowest in HDPE for all the different torques applied. In the case of wear behaviour, it’s directly proportional to torque and inversely proportional to speed. Wear rate observed was maximum for ABS and minimum for POM. The polymer gears offer the required performance and also offer weight reduction of the whole system when compared with the weight is to the transmission capacity ratio. Future research is focused on maximizing the use of polymer gears for a wide range of engineering applications.

References

[1]. Mao, K. (2007). A new approach for polymer composite gear design. *Wear*, *262*(3-4), 432-441.
[2]. Pogačnik, A., &Tavčar, J. (2015). An accelerated multilevel test and design procedure for polymer gears. *Materials & Design (1980-2015)*, *65*, 961-973.
[3]. Trobentar, B., Glodež, S., & Zafošnik, B. (2014, September). Gear tooth deflection of spur polymer gears. In *International Gear Conference 2014: 26th-28th August 2014, Lyon* (p. 129). Chandos Publishing.
[4]. Letzelter, E., Guingand, M., De Vaujany, J. P., & Schlosser, P. (2010). A new experimental approach for measuring thermal behaviour in the case of nylon 6/6 cylindrical gears. *Polymer testing*, *29*(8), 1041-1051.
[5]. Mao, K., Li, W., Hooke, C. J., & Walton, D. (2009). Friction and wear behaviour of acetal and nylon gears. *Wear*, *267*(1-4), 639-645.
[6]. Senthilvelan, S., and R. Gnanamoorthy. "Influence of reinforcement on composite gear metrology." *Mechanism and machine theory* 43.9 (2008): 1198-1209.
[7]. Hoskins, T. J., Dearn, K. D., Kukureka, S. N., & Walton, D. (2011). Acoustic noise from polymer gears–A tribological investigation. *Materials & Design*, *32*(6), 3509-3515.
[8]. Senthilvelan, S., and R. Gnanamoorthy. "Effect of rotational speed on the performance of unreinforced and glass fiber reinforced Nylon 6 spur gears." *Materials & design* 28.3 (2007): 765-772.
[9]. Senthilvelan, S., and R. Gnanamoorthy. "Effect of gear tooth fillet radius on the performance of injection molded Nylon 6/6 gears." *Materials & design* 27.8 (2006): 632-639.
[10]. Li, W., Wood, A., Weidig, R., & Mao, K. (2011). An investigation on the wear behaviour of dissimilar polymer gear engagements. *Wear*, *271*(9-10), 2176-2183.
[11]. J. Cathelin, A. Sedighiamiri, Advanced material solutions for plastic gear. Int. Gear Conference Lyon, (2014), pp.1179-1183. DOI: 10.1533/9781782421955.1179
[12]. Mertens, A. Johnney, and S. Senthilvelan. "Effect of mating metal gear surface texture on the polymer gear surface temperature." *Materials Today: Proceedings 2.4-5* (2015): 1763-1769.
[13]. Singh, Prashant Kumar, and Akant Kumar Singh. "An investigation on the thermal and wear behavior of polymer based spur gears." *Tribology International 118* (2018): 264-272.
[14]. Senthilvelan S, Gnanamoorthy R. Wear characteristics of injection-molded unfilled and glass-filled nylon 6 spur gears. Proc Inst Mech Eng Part J JEngTribol2004;218:495–502.
[15]. Bravo, A., Koffi, D., Toubal, L., &Erchiqui, F. (2015). Life and damage mode modeling applied to plastic gears. *Engineering Failure Analysis*, *58*, 113-133.
[16]. Yelle, H., & Burns, D. J. (1981, October). Root bending fatigue strength of acetal spur gears-a design approach to allow for load sharing. In *AGMA fall technical meeting*.
[17]. Fernandes, P. J. L. (1996). Tooth bending fatigue failures in gears. *Engineering Failure Analysis*, *3*(3), 219-225.
[18]. G. Bongiovanni, M. Clerico, Understanding plastic wear, Mod. Plast. 44 (1967) 126–202.
[19]. Andersson, S., & Eriksson, B. (1990, June). Prediction of the sliding wear of spur gears. In *Proceedings of the Fourth Nordic Symposium on Tribology NORDTRIB ‘90, Hirtshals, Denmark* (pp. 10-13).
[20]. Breeds, A. R., Kukureka, S. N., Mao, K., Walton, D., & Hooke, C. J. (1993). Wear behaviour of acetal gear pairs. *Wear*, *166*(1), 85-91.
[21]. Koffi, D., Gauvin, R., &Yelle, H. (1985). Heat generation in thermoplastic spur gears. *Journal of Mechanisms, Transmissions, and automation in Design*, *107*(1), 31-36.
[22]. H. Yelle, Design of thermoplastic gears with an involute tooth profileThesis (Ph. D.) University of Waterloo, 1977.
[23]. Hooke, C. J., Mao, K., Walton, D., Breeds, A. R., & Kukureka, S. N. (1993). Measurement and prediction of the surface temperature in polymer gears and its relationship to gear wear. *Journal of tribology*, *115*(1), 119-124.
[24]. Mao, K., Li, W., Hooke, C. J., & Walton, D. (2010). Polymer gear surface thermal wear and its performance prediction. *Tribology International*, *43*(1-2), 433-439

[25]. Düzcükoğlu, H. (2009). Study on development of polyamide gears for improvement of load-carrying capacity. *Tribology International*, 42(8), 1146-1153.

[26]. Hoskins, T. J., Dearn, K. D., Chen, Y. K., & Kukureka, S. N. (2014). The wear of PEEK in rolling–sliding contact–Simulation of polymer gear applications. *Wear*, 309(1-2), 35-42.

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