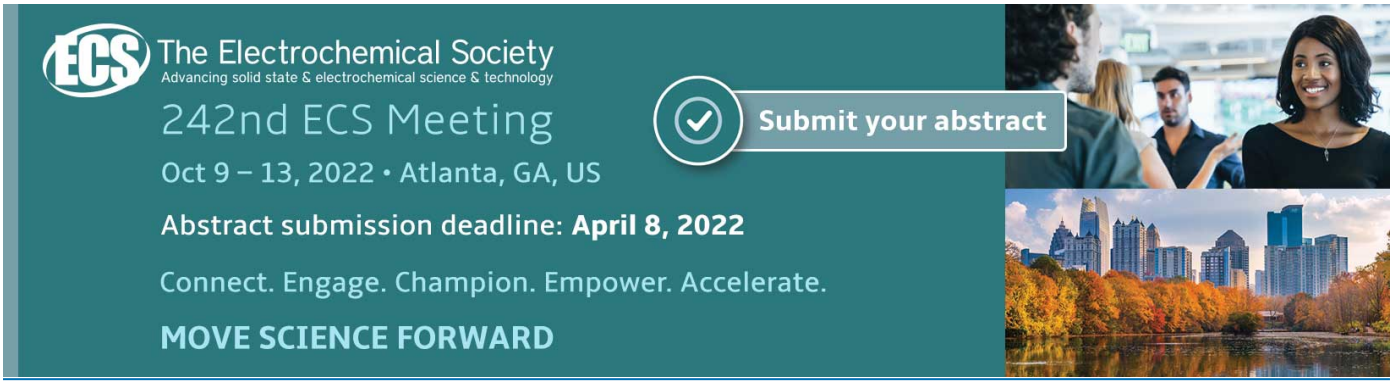
Material Selection and Processing Techniques: Crucial Factors for Gear Engineering



Material Selection and Processing Techniques: Crucial Factors for Gear Engineering

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Abstract-

Gear drives are susceptible to consistent wear due to repeated cyclic stress around the teeth while in the application. The repeated cyclic loadings have effects on the tribological performance of the components. Also, the downtime data from bottling plants showed that there is a significant increase in gear failure, which resulted in maintenance costs. The contact between a pair of gear in the mesh is complex, which leads to several failure modes like; micropitting, scuffing, micro pitting, and wear as a result of rotation. Materials formed the fundamental elements in which production/manufacturing processes depend on. The selection of materials for high-quality manufacturing depends significantly on the complicated relationship between their properties and manufacturing techniques. Recently, great varieties of materials and processing techniques are available to a gear designer. However, the choice of material and processing methods at a minimized cost poses a challenge to gear designers. In the present study, the importance of material selection and processing methods towards efficient gear design and transmission have been enumerated. Failures associated with materials and processing techniques have also been established as well as the methods of improving the mechanical properties. It is expected that the adoption of the highlighted findings into gear design would result in a reduction of failures and efficient gear transmission.

Keywords: Spur Gears, Design, Bottling Plants, Production

1. Introduction

In gear manufacturing, several aspects are combined towards efficient gear transmission design. One such which is critical and cannot be neglected is a material selection [1]. There are three fundamental factors to be considered in the choice of materials for gears, and this includes strength, durability, and cost [2]. Given this, Gupta and Chatterjee [3] noted that these factors depend on the type of gear, the environment of the application, and the combination of the mechanical properties that will give a reduced cost in large scale manufacturing. However, it is impossible to achieve excellent design without adequate manufacturing techniques during gear design. For instance, Chauby et al. [4] reported that appropriate material selection connotes better manufacturing methods, which will give accurate, functional, and excellent operation of gears with long service life.

Further to this, Chaubey et al. [5] applied a multi-response optimisation technique in the manufacturing of helical gears to achieve desirable qualities such as uniform bore and good flank surface. In recent years, the selection of gear material depends on the environment for the application, and proper material selection selections will help in reducing material failure [6, 7]. More so, non-metallic materials for gears provide smooth transmission with less noise and vibration. Thus fatigue is reduced in this type of gears [8, 9]. Off course, gear failure could cost excessive downtime, reduce equipment reliability as well as reducing product quality [10, 11]. The functional properties and manufacturing techniques, as well as the cost of materials, are significant factors influencing the choice of materials. for instance, Gupta et al. [12] noted that laser treatment of steel gears is cost-effective and enhances the service life of SAE8620HVD steel gears. Also, surface durability depends on compressive strength and hardness, thus, having an overall effect on the tribological behavior of the gear [13, 14]. The performance of gear material is improved when a human decision is recognised. Therefore, gear designers need to strike a balance between hardness and strength of the gear for optimum performance during application [15]. Based on this, it is essential to control the material and processes during gear manufacture as variation in the composition and microstructure affects the quality and performance of the product [16-18]. Specific criteria for material selection can be based on the coefficient of thermal expansion, yield strength, and creep strength [19]. These properties are usually found in composite spur gears, which made them preferable to steel gears for most applications [20].

2. Importance of Materials and Processing techniques to strength Characteristic of Gears

Gears are made of different materials depending on the machine requirement. For smooth transmission, durability, and reliability, material selection for gear application is essential. For instance, high load types of machinery need a hard and tough material. Thus, a gear designer is faced with material selection challenges. Different types of steel are mostly used for gear materials due to their versatile nature in meeting specifications and applications. Also, their strength, availability, and low cost are the primary reasons for their usage [21-23]. Surface treatment of steel based materials gives better tensile and fatigue properties when subjected to cyclic loading due to improved microstructure and hardness [24,25]. [26-29] noted that adequate material selection and processing methods greatly influence their performance in application and environment. Also, poor surface finishing and gear assembly problems contribute to the gear downtime and overall equipment reliability [30]. Thus, strength characteristics and tribological behavior of steel gears are functions of material property combination [31-33].

3. Gear failure due to material selection and processing techniques

The way to measure vibration, shocks, and noise level of a newly developed gear for any application is through testing. This is quite complex to inspect into the quality process during the design stage (material selection). However, applying a feedback mechanism that can reveal the different interactions within the component will aid a gear specialist in analysing the material performance [34,35]. Thus, crack formation, which causes gear failure, is easily detected via this interactive feedback mechanism [36], as well as pitting progression [37]. Dengo et al. [38] reported that material testing is cheaper and safer during gear design as it provides the chance of identifying the mechanical properties of such as microhardness, strength, fatigue behavior before putting it into the application. This possibly will prevent several failure occurrences such as misalignment, stress at the point of contact during

operation, as represented in figure 1. Fig.1 showed the axial and radial misalignment test of a pair of gears in mesh. Consequently, the possibility of failure due to misalignment will reduce [39].

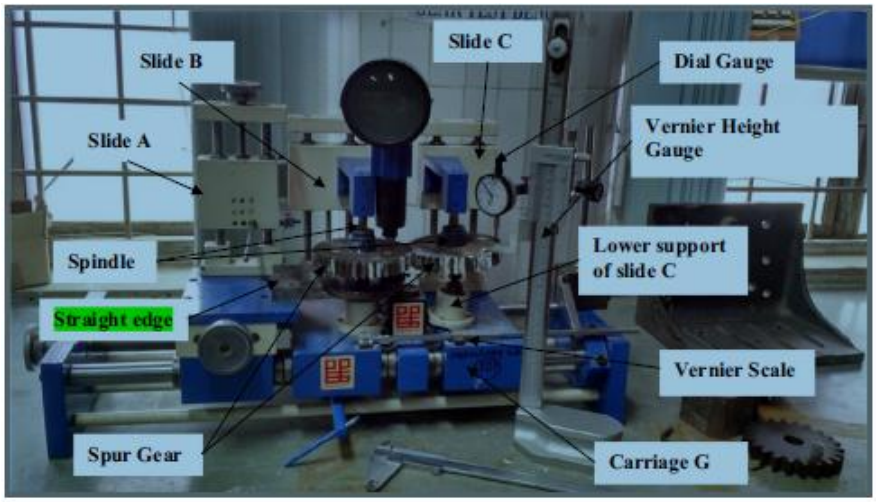

Fig. 1: Spur Gear misalignment test set-up [39].

Recently, fatigue and corrosion of gears is a great challenge to gear design due to different application environment, thus the need to optimize materials and processing methods [40]. Additionally, Franulovic et al. [41] noted that the optimal approach of gear design involves adequate size, geometry determination, materials, and proper manufacturing techniques. These factors contribute to the efficient performance and life span of the gear. Inadequate material selection to meet these performance criteria would lead to failures. Pitting constitutes a significant failure factor in components in rolling or sliding contact, especially gears. The loads are carried by small radii of the curve resulting in high pressure and stress. Crack initiation is set in due to the repeated cyclic stress resulting in material removal and reducing the tribological behavior of the gear systems [42-48]. However, the proper involute design would improve the velocity ratio during transmission, and consequent thermal stress generated [49,50].

Conclusion

Increasing failures in gears have become a crucial factor in determining the availability and reliability of gears, especially in bottling plants. Subsequently, noise, shocks, and gear vibrations are factors that cannot efficiently be designed into the component, and these behaviors are evident during operation. To achieve appropriate gear design to eliminate failure and maintenance costs, material selection, and processing methods played crucial factors. Thus, various failure resulting from improper material and processing techniques have been established. Adequate material selection and near-surface treatment techniques reduced surface fatigue and improved the performance of gears.

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Reference

[1] Delibaş, H., Uzay, Ç., & Geren, N. Advanced Material Selection Technique for High Strength and Lightweight Spur Gear Design. European Mechanical Science, 1(4), 133-140.

[2] Chatterjee, P., & Chakraborty, S. (2013). Gear material selection using complex proportional assessment and additive ratio assessment-based approaches: a comparative study. International Journal of Materials Science and Engineering, 1(2), 104-111.

[3] Gupta, K., & Chatterjee, S. (2018). Analysis of design and material selection of a spur gear pair for solar tracking application. Materials Today: Proceedings, 5(1), 789-795.

[4] Chaubey, S. K., & Jain, N. K. (2018). State-of-art review of past research on manufacturing of meso and micro cylindrical gears. Precision Engineering, 51, 702-728.

[5] Chaubey, S. K., & Jain, N. K. (2019). Analysis and multi-response optimization of gear quality and surface finish of meso-sized helical and bevel gears manufactured by WSEM process. Precision Engineering, 55, 293-309.

[6] Wang, Y., Ren, S., & Li, Y. (2019). Design and manufacturing of a novel high contact ratio internal gear with a circular arc contact path. International Journal of Mechanical Sciences, 153, 143-153.

[7] Lisle, T. J., Shaw, B. A., & Frazer, R. C. (2017). External spur gear root bending stress: a comparison of ISO 6336: 2006, AGMA 2101-D04, ANSYS finite element analysis and strain gauge techniques. Mechanism and Machine Theory, 111, 1-9.

[8] Evans, S. M., & Keogh, P. S. (2019). Wear mechanisms in polyoxymethylene spur gears. Wear.

[9] Wernicke, S., Gies, S., & Tekkaya, A. E. (2019). Manufacturing of hybrid gears by incremental sheet-bulk metal forming. Procedia Manufacturing, 27, 152-157.

[10] Salawu, E. Y., Ajayi, O. O., Inegbenebor, A. O., Afolalu, S. A., & Ongbali, S. O. (2018). Pareto Analysis of Product Quality Failures and Cost Effects in Bottling Machines-A Lean Thinking Solution for Alcohol Industry. International Journal of Mechanical Engineering and Technology, 9(11), 2380-2388.

[11] Yekini, S. E., Okokpujie, I. P., Afolalu, S. A., Ajayi, O. O., & Azeta, J. (2018). Investigation of production output for improvement. International Journal of Mechanical and Production Engineering Research and Development, 8(1), 915-922.

[12] Gupta, H. S., Hussain, M., Singh, P. K., Kumar, V., Kumar, S., & Das, A. K. (2019). Laser Surface Modification of SAE8620 HVD Material for Transmission Gear. Materials Today: Proceedings, 11, 813-817.

[13] Kong, W., Zhang, D., Tao, Q., Chen, K., Wang, J., & Wang, S. (2019). Wear properties of the deep gradient wear-resistant layer applied to 20CrMnTi gear steel. Wear, 424, 216-222.

[14] Bharti, S., & Selvaraj, S. (2019). Effects of lubricant on the surface durability of an injection molded polyamide 66 spur gear paired with a steel gear. Tribology International.

[15] Das, D., Bhattacharya, S., & Sarkar, B. (2016). Decision-based design-driven material selection: A normative-prescriptive approach for simultaneous selection of material and geometric variables in gear design. Materials & Design, 92, 787-793.

[16] Wu, T., Wang, G., Li, J., & Yan, K. (2018). Investigation on gear rolling process using conical gear rollers and design method of the conical gear roller. Journal of Materials Processing Technology, 259, 141-149.

[17] Geradts, P., Brecher, C., Löpenhaus, C., & Kasten, M. (2019). Reduction of the tonality of gear noise by application of topography scattering. Applied Acoustics, 148, 344-359.

[18] Wang, L., Shao, Y., & Cao, Z. (2018). Optimal demodulation subband selection for sun gear crack fault diagnosis in planetary gearbox. Measurement, 125, 554-563.

[19] Zindani, D., & Kumar, K. (2018). Material Selection for Turbine Seal Strips using PROMETHEE-GAIA Method. Materials Today: Proceedings, 5(9), 17533-17539.

[20] Pawar, P. B., & Utpat, A. A. (2015). Analysis of composite material spur gear under static loading condition. Materials Today: Proceedings, 2(4-5), 2968-2974.

[21] Darji, V. P., & Rao, R. V. (2014). Intelligent multi criteria decision making methods for material selection in sugar industry. Procedia Materials Science, 5, 2585-2594.

[22] Sammaiah, P., Sneha, M., Khaseem, M., & Kumar, N. S. (2018). Effect of Heat Treatment & Machining Process for Deposition of Al2O3 Nano Particles on Steel. Materials Today: Proceedings, 5(2), 6453-6460.

[23] Bertuccioli, C., Ceschini, L., & Martini, C. (2019). Steel components for packaging devices in sliding/rolling contact: Metallurgical failure analysis. Engineering Failure Analysis.

[24] Kumar, S., & Ghosh, P. K. (2018). TIG arc processing improves tensile and fatigue properties of surface modified of AISI 4340 steel. International Journal of Fatigue, 116, 306-316.

[25] Mohan, N., & Arul, S. (2018). Effect of Cryogenic Treatment on the Mechanical Properties of Alloy Steel 16MnCr5. Materials Today: Proceedings, 5(11), 25265-25275.

[26] Anojkumar, L., Ilangkumaran, M., & Sasirekha, V. (2014). Comparative analysis of MCDM methods for pipe material selection in sugar industry. Expert Systems with Applications, 41(6), 2964-2980.

[27] Markovic, S. L., & Lazovic, T. M. (2014). Technological heredity–A decisive factor for tribological features of regenerated gears. Engineering Failure Analysis, 42, 121-132.

[28] Pierce, D., Haynes, A., Hughes, J., Graves, R., Maziasz, P., Muralidharan, G., ... & Daniel, C. (2018). High temperature materials for heavy duty diesel engines: historical and future trends. Progress in Materials Science.

[29] Kumar, R., & Singal, S. K. (2015). Penstock material selection in small hydropower plants using MADM methods. Renewable and Sustainable Energy Reviews, 52, 240-255.

[30] Fontanari, V., Benedetti, M., Straffelini, G., Girardi, C., & Giordanino, L. (2013). Tribological behavior of the bronze–steel pair for worm gearing. Wear, 302(1-2), 1520-1527.

[31] Kalin, M., & Vižintin, J. (2005). The tribological performance of DLC-coated gears lubricated with biodegradable oil in various pinion/gear material combinations. Wear, 259(7-12), 1270-1280.

[32] Ravivarman, R., Palaniradja, K., & Sekar, R. P. (2018). Influence of gear ratio on wear depth of nonstandard HCR spur gear drive with balanced fillet stress. Materials Today: Proceedings, 5(9), 17350-17359.

[33] Beilicke, R., Bobach, L., & Bartel, D. (2016). Transient thermal elastohydrodynamic simulation of a DLC coated helical gear pair considering limiting shear stress behavior of the lubricant. Tribology International, 97, 136-150.

[34] Milani, A. S., Shanian, A., Lynam, C., & Scarinci, T. (2013). An application of the analytic network process in multiple criteria material selection. Materials & Design, 44, 622-632.

[35] Pogačnik, A., & Tavčar, J. (2015). An accelerated multilevel test and design procedure for polymer gears. Materials & Design (1980-2015), 65, 961-973.

[36] Belsak, A., & Flasker, J. (2006). Method for detecting fatigue crack in gears. Theoretical and Applied Fracture Mechanics, 46(2), 105-113.

[37] Kundu, P., Darpe, A. K., & Kulkarni, M. S. (2019). A correlation coefficient based vibration indicator for detecting natural pitting progression in spur gears. Mechanical Systems and Signal Processing, 129, 741-763.

[38] Dengo, C., Meneghetti, G., & Dabalà, M. (2015). Experimental analysis of bending fatigue strength of plain and notched case-hardened gear steels. International Journal of Fatigue, 80, 145-161.

[39] Kumar, P., Hirani, H., & Agrawal, A. K. (2019). Effect of gear misalignment on contact area: Theoretical and experimental studies. Measurement, 132, 359-368.

[40] Igwemezie, V., Mehmanparast, A., & Kolios, A. (2018). Materials selection for XL wind turbine support structures: A corrosion-fatigue perspective. Marine Structures, 61, 381-397.

[41] Franulovic, M., Basan, R., Kunc, R., & Prebil, I. (2011). Numerical modeling of life prediction of gears. Procedia Engineering, 10, 562-567.

[42] Terrin, A., Dengo, C., & Meneghetti, G. (2017). Experimental analysis of contact fatigue damage in case hardened gears for off-highway axles. Engineering Failure Analysis, 76, 10-26.

[43] Ahlroos, T., Ronkainen, H., Helle, A., Parikka, R., Virta, J., & Varjus, S. (2009). Twin disc micropitting tests. Tribology International, 42(10), 1460-1466.

[44] Weibring, M., Gondecki, L., & Tenberge, P. (2019). Simulation of fatigue failure on tooth flanks in consideration of pitting initiation and growth. Tribology International, 131, 299-307.

[45] Mallipeddi, D., Norell, M., Sosa, M., & Nyborg, L. (2019). The effect of manufacturing method and running-in load on the surface integrity of efficiency tested ground, honed and superfinished gears. Tribology International, 131, 277-287.

[46] Oila, A., & Bull, S. J. (2005). Assessment of the factors influencing micropitting in rolling/sliding contacts. Wear, 258(10), 1510-1524.

[47] Martins, R., Seabra, J., & Magalhaes, L. (2008). Austempered ductile iron (ADI) gears: Power loss, pitting and micropitting. Wear, 264(9-10), 838-849.

[48] Al-Tubi, I. S., Long, H., Zhang, J., & Shaw, B. (2015). Experimental and analytical study of gear micropitting initiation and propagation under varying loading conditions. Wear, 328, 8-16.

[49] Salawu, E. Y., Okokpujie, I. P., Ajayi, O. O., & Agarana, M. C. (2018). Analytical technique for the determination of hoop stress and radial stress on the tooth spur gear under vertical loading in a food packaging machine.

[50] Salawu, E. Y., Okokpujie, I. P., Ajayi, O. O., Afolalu, S. A., & Agarana, M. C. (2018). Numerical modeling and evaluation of involute curve length of a spur gear tooth to maintain constant velocity ratio while in motion.