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Effects of Heat Treatment Techniques on the Fatigue Behaviour of Steel Gears: A Review

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Abstract

Heat treatment of gears are fundamental to efficient and reliable gear production because of its contribution to the overall cost of manufacturing. Different heat treatment techniques are targeted to improving hardness, ductility and strength to minimize material degradation or wear. However, several heat treatment methods had led to gear tooth distortion such as shrinkage of tooth thickness which eventually affects the contact angle. The study therefore focused on some selected heat treatment on gears and their effects on gear applications. from the reviewed heat treatment techniques, distortion is a common occurrence that result to gear fatigue. Also, it was noted that most times, the medium for quenching and most importantly, variation in the concentration affects the gear accuracy. Thus, local fracture and material loss ensue. Nevertheless, the study further suggested the use of empirical model and simulation approach for stress prediction.

Keyword; Fatigue, Spur Gear, Heat treatment, Production

1. Introduction:

Heat treatment is a fundamental step in the manufacturing process of gears. It involved the structural integrity modifications of the material which includes physical, chemical and metallurgical characteristics to optimize the mechanical properties for better and reliable performance in service. Different type of heat treatment can be highlighted based on the part of gear to be heat treated. They include nitriding, nitrocarburization, case hardening, carbonitriding and direct hardening [1]. Despite the importance of heat treatment on gears, there seems to be critical issues associated with the post heat treatment assessment such as distortion resulting from forged gears thereby affecting the gear teeth strength and overall dimensional accuracy [2, 3]. Some heat treatment process shows their wear behaviour on the surface of the gear mainly by contact fatigue which usually result to pitting and surface crack [4]. Studies have showed that shot peened gears have increased hardness properties and the stress at the surface of the gear teeth was transformed from tensile to compressive. However, a major drawback of compressive stress for a pair of mating gears is the bending which usually result to a single tooth carrying the entire load and this can cause catastrophic failure of the teeth [5-6]. Fujisawa and Komori. [7], reported that it was possible to eliminate distortion in gears as a result of heat treatment by using a carbide hob to re hob the gear. Consequently, this approach usually leaves a dent on the gear tooth surface which reduces the strength during operation. Based on this, Kim et al. [8] developed a finite element model to predict parameters such as phase change, hardness distribution and dimensional change during carburization.

2. Case hardening of steel Gears

This involved the heating of medium and high carbon steel under a controlled carbon distribution to form a gear with harder surface in order to resist abrasive wear. Case hardening process offers excellent mechanical properties such as surface hardness and increased compressive residual stress, yet associated with certain problems involving contact fatigue [9].



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In the study of wind turbine performance by Karpuschewski et al. [10], wind turbines that delivers higher megawatt are supposed to be designed with gears of high hardness because of the high load carrying capacity. However, the mechanism of the contact fatigue remains a major problem as it affects the machine reliability [11]. Obviously, the fatigue failures of gears increases as the demand for power transmission increases because of the integral effect of the gear tooth surface roughness and the increased loading condition [12]. Nevertheless, a significant impact of bending fatigue can be achieved on an induction hardened gear surface through the residual stresses [13-15]. Consequently, the hardenability of gears can be predicted using modelling and simulation approach since the hardness produces a martensitic structure at the surface of the gear tooth and also compressive residual stresses. In essence it will be possible to reduce the contact fatigue behaviour of mating gears [16-19]. Studies have showed that hardened layers of steel materials usually display abrasive wear properties at low load, while the unhardened materials exhibit critical failure during endurance test [20-24].

3. Nitriding and carburization of Gears

Nitriding is a heat treatment technique which involved the diffusion of nitrogen into the metal to produce a hardened surface. This thermal treatment is mostly done on low-carbon and low-carbon and alloy –steels yet having a higher wear rate. Assessment of the micropitting behaviour of a nitride gears revealed that there was increased mass loss of gear after several test at different loads [25,26]. Also, uncontrolled parameters during nitriding process can lead to hardness variation in gears even though it shows great improvement in the hardness [27,28]. To prevent the mass loss, surface hardness of the gears should always be improved while nitrided gears operate efficiently under controlled operating speed to avoid fatigue cracking [29,30]. Further to this, longer hours is required to be able to get the required thickness layer of nitrogen deposit on the surface of the gear during nitiding process and plasma nitrided gears have combine wear mechanism which include adhesive, abrasive and plastic yielding mechanism [31-34].

Carburization refers to a heat treatment procedure that improves the wear properties and maintaining the strength of steel materials. it is usually carried out in a furnace using carbon materials and under high temperature and the material is usually quenched in different media to achieve a martensitic structure. Carburized gears are usually associated with contact fatigue issues which causes serious tooth deformation and variation in addendum circle due to long hours of experiment as well as grain coarsening [34-36]. More so, during the quenching process, there is expansion in the case and at the interior region which eventually causes dimensional inaccuracy on the component geometry [37,38].

Consequently, the error in manufacturing of gears poses operational problem during application. For instance, Salawu et al. [39,40] reported that thermal stresses occur where there is expansion at the involute tooth and the whole gear body. However, defects and errors can be corrected by process modelling and simulation. This will guide and help in predicting the common defects thereby having a reliable and efficient design [41-43].

Conclusion

Fatigue stress occur due to contact between two mating gears. Repeated cyclic stress would result to total deformation. Distortion of gears are mostly found around variation in process parameters during heat treatment. Therefore, to reduce gear distortion, heat treatment techniques have been studied to determine which method contribute gear distortion. From the reviewed work, distortion of heat treated gears are always higher in carburized or case hardened gears due to media concentration and quenching mechanism compared to induction hardened gears. Thus, it is important to study the parameters which can be optimised during the processes

to reduce the possibility of distortion. Also quenching medium of high convective heat transfer will be appropriate for hardness increase. In this case, water has this property.

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