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EFFECTS OF TORQUE AND SPEED ON THE WEAR BEHAVIORS OF STEEL AND POLYOXYMETHYLENE PLASTIC SPUR AND HELICAL GEARS

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ABSTRACT

Wear resistances of steel and plastic spur and helical gears under the certain loads (torques) and rotational speeds were investigated in this study. Steel and plastic gears were manufactured using injection molding and machining processes, respectively. The weight and tooth thickness of the steel and PolyOxyMethylene (POM) gears were equal to each other, and the sizes of the gears were determined by the modification of the module and the diameters of the gears. The influences of torque (5, 10 and 15 Nm) and rotational speed (50, 100 and 150 rpm) on the wear resistance of the gears were studied using the gear-on-gear wear testing method. The weight loss of all steel and plastic spur and helical gears increased due to wear as the torque and speed increased. The wear resistance of steel and POM helical gears was higher than that of steel and POM helical gears. Although the wear resistance of steel gears was better than that of POM gears, their values were close to each other. The results showed that POM helical gears can be preferred over steel gears in some applications because of the advantages of plastic gears, such as low cost, no lubrication requirements, and high corrosion resistance.

Keywords: Plastic gear, Polyoxymethylene (POM), Spur gear, Helical gear, Wear resistance.

1. INTRODUCTION

Engineering plastics are a group of plastic materials that possess outstanding and extensive properties, such as less creep, strong corrosion resistance, electrical insulation, ease of processing, etc. They have therefore been extensively used in equipment, aerospace, electronics, construction, chemical and other industries (Crompton, 2014; Shrivastava, 2018).

Gears used as a machine element can be made from a variety of materials, including several types of steel, brass, copper, cast iron, titanium, metals, and plastics. Plastic-based gears are used in a number of applications, such as food processing devices, consumer goods, industrial, and medical equipment (Dong et al., 2015). Trade volume of gears continues to increase year on year. Market output of all gears, the Global Gear Engineering Market estimated at $127.81 billion in 2018, is projected to rise by 5.9% between 2019 and 2026 and to reach $200.10 billion in 2026. On the other hand, the Global Plastics Gears industry is estimated to be worth USD 3137.8 million in 2020. Expected to increase by 1.2 percent by the end of 2026 to reach $3414.3 million by the end of 2026 (Verified Market Research, 2019).

Gears are manufactured in various forms to fulfill these specifications, based on factors such as load and rpm. Helical gears are favored for heavy loads and speeds. Spur gears are chosen because of their low cost of manufacturing, they do not transfer axial force and are simple to manage. Bevel gears are used to shift the rotation to another spindle that intersects with the axis of the spinning shaft and, where possible, to provide speed conversion.

Important considerations in the manufacture of plastic gears include adequate strength, lightness, quiet operation, ease of processing, etc. Depending on these factors, the geometry and type of the gear are determined and developed (Sachidananda et al., 2015). Load and speed are the most effective parameters for determining the geometry of the gears**.**

Hlebanja et al. (2019) also decided that the use of plastic products relies on several factors and that each plastic requires to be checked in a particular way. For this reason, he researched the wear of spur gear from each mixture.

Ghazali et al. (2017) has established that polymer gears, which are now favored over steel gears in the market, have different failures. In order to assess these specific situations, it studied the wear of various plastic structures and gears with different geometries.

For plastic gears, the temperature not only influences the strength of the gear but also the structure. Among such purposes, in the design of the gear geometry, the thermal conductivity of the material as well as the gear geometry and the gear module should be addressed (Kashyap et al., 2011).

Singh et al. (2018) developed gears utilizing three separate polymer gear materials. Through adding various rotational speeds and torques to these gears, he studied the failure modes of the gears and noted the wear on the teeth.

The degree of wear of the revolving and moving gears of the co-operating gear pair of polymer gears varies from each other. A specific geometry may therefore be generated by evaluating the configuration of the revolving gear using the finite element rule (Mao et al., 2019).

Different damage to the teeth occurs with the application of plastic gears. Because the mechanical properties of each gear are specific, the optimal performance of the gear can be obtained by thinking about the errors that may arise in the gear and when they arise (Bravo et al., 2015).

Gear wheels are elements typically used in virtually any high-end device in today's technology used to optimize motion transmission. For this purpose, in the manufacture of gears, depending on where the gear is used, ample power, lightness, economy, quiet function, simple output, long life, size difference, etc. Issues such as the most relevant design criterion for the gear wheel can be defined. Using plastic parts to meet these specifications, the characteristics of gear wheels such as noise-free operation, oil-free operation, lightness, and vibration absorption are economical. These advantages of plastic gear have led this study to research on this subject.

Works on plastic gears described above have been studied on spur gears, in fact, helical gears have higher load efficiency compared to spur gears. POM plastic helical gear was therefore developed and its wear behavior was studied and compared to steel gears depending on load and speed.

2. MATERIALS AND METHODS

Wear behaviors of helical gears produced from polyoxymethylene (POM) plastic were investigated in this study and also compared to those of spur gears and steel spur and helical gears.

Plastic and steel gears were produced by using the injection molding and machining processes, respectively. Plastic- and steel-based spur and helical gears were manufactured at the same weight and thickness (Figures 1 and 2). Geometries of the gears were determined in such as a way that the gears had the same weight.

In the operating theory of the experimental system, the weight loss of the gears due to wear was investigated by measuring the weight loss of the two gears attached to the shafts. With the help of the piston, a torque of certain force ranges was provided by the first spinning gear shaft in the device. By applying a certain weight to the shaft where the revolving gear is mounted, the wear of the gears was investigated along with the moment of forming, based on the distance of weight. Such procedures were carried out by means of torques and weights composed of various forces, and the wear action of the gears under specific conditions was attempted.

The wear tests were carried out under different torques (5, 10, and 15 Nm) and rotational speeds (50, 100, and 150 rpm). The gears were weighted before and after the wear tests in order to measure the weight loss of the gears.

In addition to the experimental test, finite element process was performed to analyze the stress and strain formed in the gears.

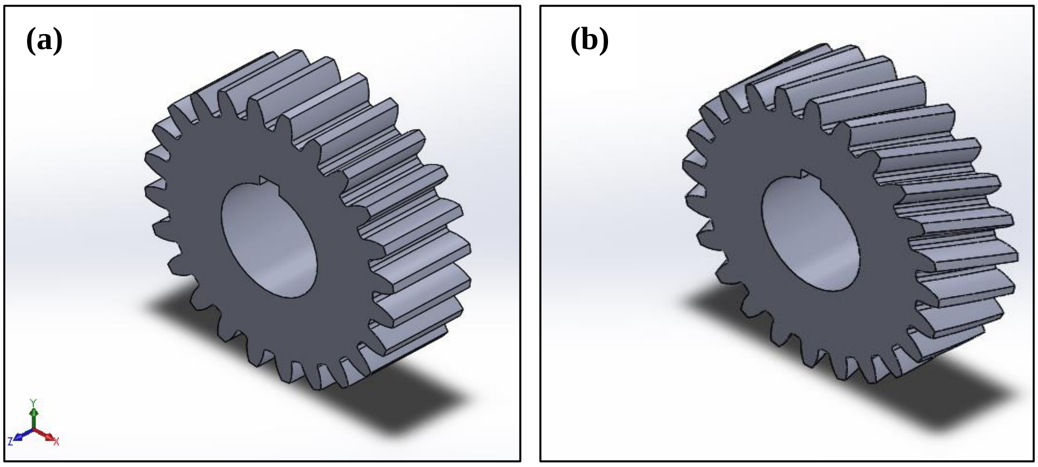

Figure 1. Solidworks drawing images of POM (a) spur and (b) helical gears

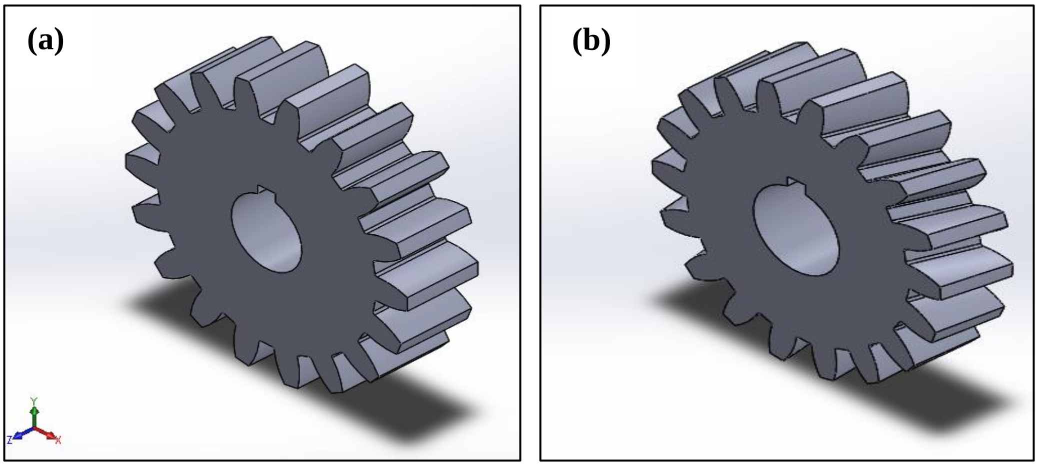

Figure 2. Solidworks drawing images of steel (a) spur and (b) helical gears

3. RESULTS AND DISCUSSION

Figures 3 and 4 shows the weight loss of the spur gears manufactured from polyoxymethylene (POM) and steel. The experimental results showed that the weight loss of the POM and steel spur gears increased with the increase in torque; similarly, with the increase in rotational speed, the weight loss of the POM and steel spur gears increased as seen in Figures 3 and 4.

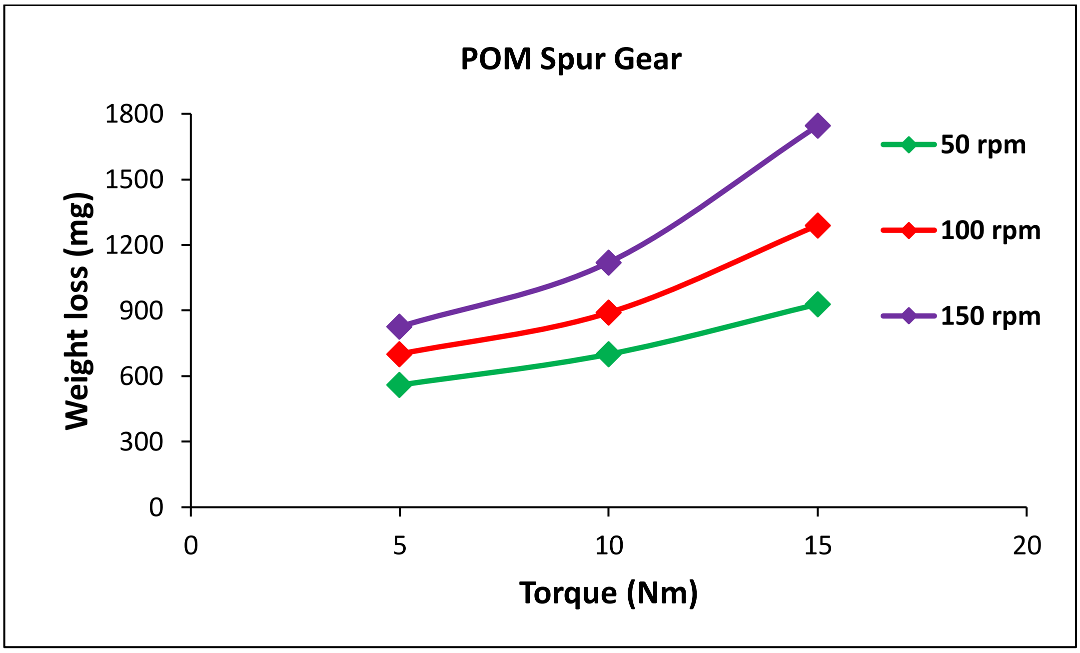

Figure 3. Weight loss of POM spur gear depending on torque and rotational speed

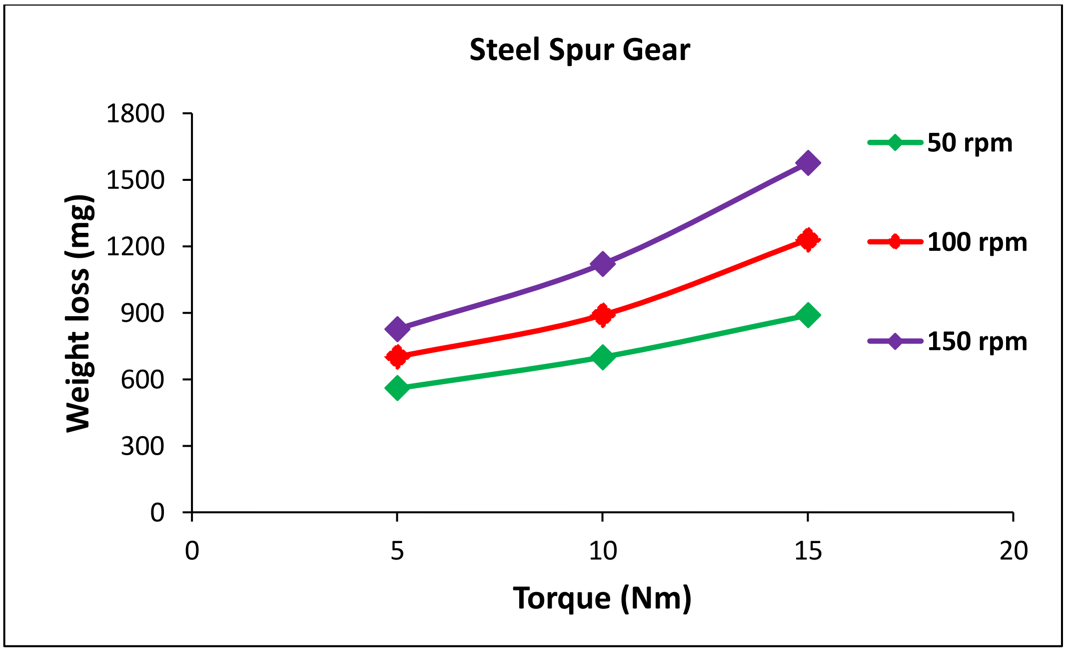

Figure 4. Weight loss of steel spur gear depending on torque and rotational speed

The weight loss of the POM spur gear was higher than that of the steel spur gear due to its lower strength and temperature resistance. On the other hand, the increase in weight loss of both steel and POM gears was higher at the high torque and rotational speeds. The strength of POM plastic is lower than that of steel. According to the results of the finite element analysis, as seen in Figure 5 and 6, the maximum and high stresses occurred on the contact area between the tooth couple, the line-of-action, and the tooth root of the gear (Vera et al., 2012). Moreover, high-stress fields (or regions) in POM spur gear were larger than thoset of steel spur gear. For these reasons, the wear resistance of the POM spur gear was lower than that of the steel spur gear.

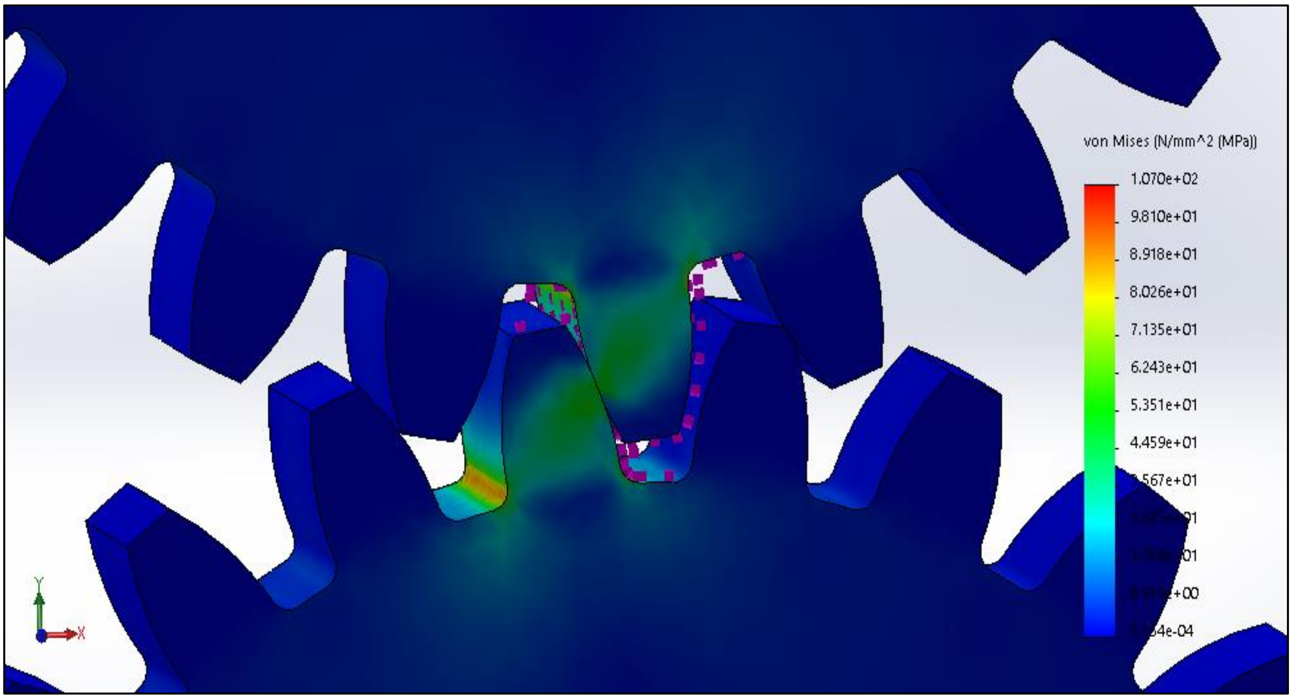

Figure 5. Finite element analysis of stress distribution of POM spur gear

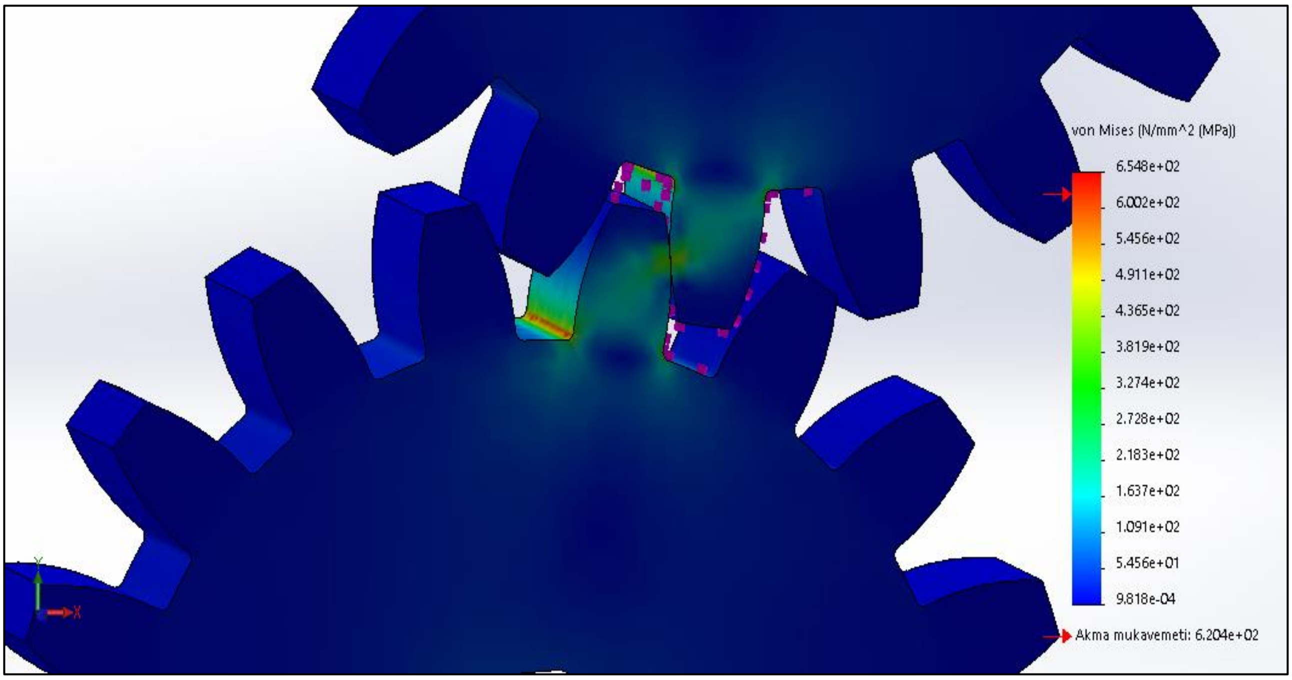

Figure 6. Finite element analysis of stress distribution of steel spur gear

Compared to steel gears, the significant drawback in the wear behavior of plastic gears is the failure of the wear resulting from the melting due to the formation of high temperatures in the conditions where load and speed are high (Shing et al. 2018; Tavčar et al., 2018; Ghazali et al., 2017; Li et al. 2011; Kalacska et al., 2005). However, for the same weight, the sizes of the plastic gear is larger than those of the steel gear. This may contribute to an increase in the heat transfer from the gear, resulting in a delay in damage (Ghazali et al., 2017).

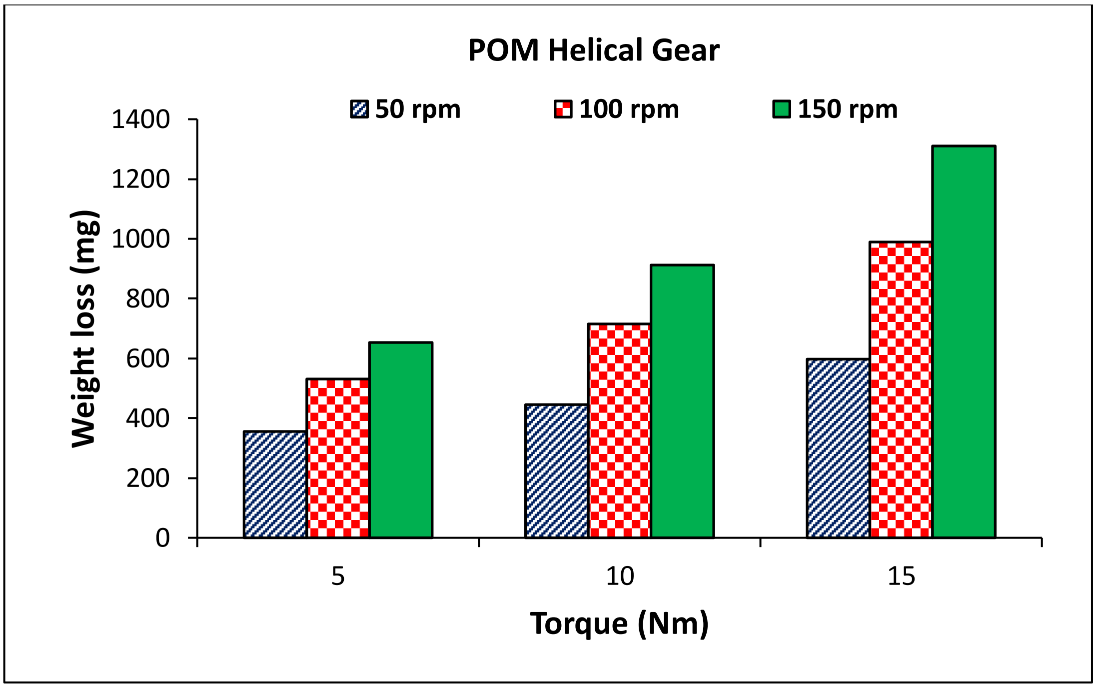

Figure 7. Weight loss of POM helical gear depending on torque and rotational speed

POM helical gear has been developed to improve the wear resistance of the POM gear. In addition, the steel helical gear was manufactured to be compared to the POM helical gear. Figures 7 and 8 shows the weight loss of helical gears made of polyoxymethylene (POM) and steel. The weight loss of the POM and steel helical gears increased with the increase of the torque; similarly, with the increase of the rotational speed, the weight loss of the POM and steel spur gears increased.

The weight loss of the POM and steel helical gears was lower than that of weight loss of the POM and steel spur gears because the number of contact surface and tooth in contact with each other at the same time at the helical gears and is greater than that of the spur gear, which leads to a decrease stress level on the tooth of the gears, resulting in an increase in wear resistance of helical gears (Shing et al. 2018).

Although the wear resistance of steel gears was better than that of POM gears, their values were close to each other. The results showed that POM helical gears can be preferred over steel gears in some applications because of the advantages of plastic gears, such as low cost, no lubrication requirements, and high corrosion resistance.

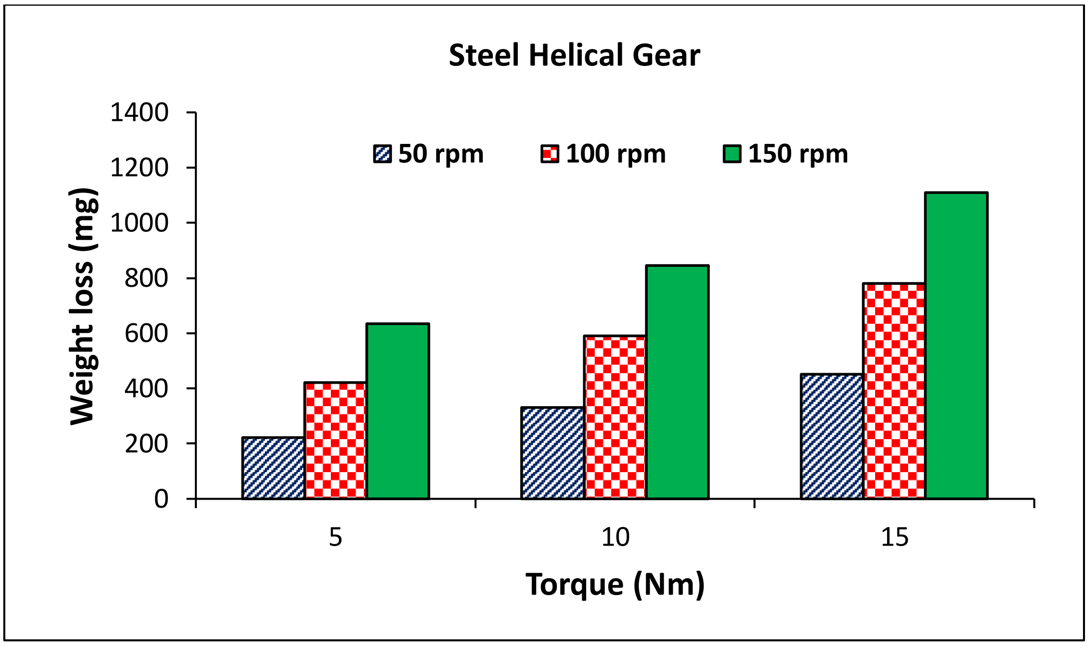

Figure 8. Weight loss of steel helical gear depending on torque and rotational speed

4. CONCLUSIONS

In this study, spur and helical gears with the same weight and thickness were manufactured from polyoxymethylene (POM) and steel materials using injection molding and machining processes. The effects of the load and speed variables on the wear properties of POM- and steel-based spur and helical gears were investigated and the wear properties of all gears were compared to each other.

The weight loss of all gears decreased due to wear as the load and speed increased. Due to the occurrence of a large number of wear mechanisms, the gears were exposed to a higher amount of wear at high load and speed values. In terms of the type of gear, the helical gears had a higher wear resistance than the spur gears for both of POM- and steel-made gears. Depending on the load and speed, although the weight loss of steel gears was found to be lower than that of POM plastic gears, the weight loss of both steel and POM gears were close to each other. It can, therefore, be concluded that helical plastic gears are more advantageous than steel gears under certain conditions where the load and speed are not very high, taking into consideration the advantages of plastic gears such as no lubrication requirements, quieter operation, corrosion insensitivity, and lower costs when compared to steel gears under conditions.

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