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THE EFFECT OF INTERFERENCE ON THE FRICTION TORQUE CHARACTERISTICS OF TPU BASED ROTARY LIP SEALS

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Abstract: *The effects of radial force (interface) produced by interference on the static contact properties and frictional characteristics of a radial lip seal are investigated by experiments. For this reason a test system has been developed. In this test system a cylinder is placed on four load cells in order to monitor the moment generated between seal and counterface. A group of experiments are done with thermoplastic polyurethane radial lip seals. Three different inner diameters (40, 39.80 and 39.60 mm) are selected and the seals are tested under 0.5 and 0.3 bar for a short period. The frictional torque was measured and compared for different inner diameters. As a result, it is observed that the amount of interference effects seal friction torques based on seal material and seal design in different ratios.*

Keywords: *rotary lip seals, interference, friction torque, leakage, PU.*

1. INTRODUCTION

The radial force is a critical factor which affects the sealing performance in rotary lip seals. If the radial force is too large, high friction and wear will occur. If the radial force is too small, seal can leak since the vibrations and eccentricity cannot be followed. The radial force should be large enough in order to prevent leakage. Some amount of the total radial force is produced by garter spring and the remaining part is produced by elastic deformation of elastomer which occurs because of the interference between the elastomer ring and the shaft. Therefore, it is important to determine the suitable interference and garter spring force values in order to provide enough radial force. Thus, the elastomer wear and aging can be controlled. At the same time, friction torque should be kept as low as possible in order to save energy.

Many researchers investigated radial force phenomenon both numerically and experimentally. Jia et al. studied on the effects of radial force produced by garter spring and interference on the static contact properties and sealing performance of a radial lip seal by numerical simulations and experiments. They found a critical value of interference for a cost-effectively designed radial lip seal and studied on controlling sealing performance by using garter spring [1]. Plath et al. analyzed the effect of speed, temperature and radial force on friction torque values of a radial lip seal [2]. Keitzel et al. developed a radial force measurement system [3]. Gabelli et al. studied on measuring the sealing contact stress and its role in rotary lip seal design. They examined the sealing contact stress distribution for five different interferences [4]. Guo et al. decreased the interference of a radial lip seal from 0.914 mm to 0.686 mm and examined the effect of this change on pumping rate and friction torque [5]. A similar study has been carried out by Gül et al. using same test system. In this work, friction and wear characteristics of PTFE seals with elastomer lip have been investigated experimentally [6].

2. EXPERIMENTAL SET-UP

To investigate the effect of the radial force produced by interference on the frictional characteristics of radial lip seal, a test rig was developed for the systematical experiments (Fig. 1). The test block and the cover were made of aluminium to obtain relatively good thermal properties. The radial lip seals were mounted to the cover on the cylinder block (Fig. 1). To prevent the oil leakage between cover and block, an O-ring was placed to the system. High pressure industrial gear oil with 150 cSt viscosity having a density of 897 kg/m^3 at 15 °C was used as lubricant in the experiments. Test system is driven by a frequency controlled AC motor. A flat belt mechanism was coupled to the motor in order to obtain the desired speeds for experiments. Rotational speed of the disc is measured by an optical tachometer. Radial force of seal due to its design generates a frictional force when shaft starts to rotate. As seen in the Figure 1, four force transducers (load cells) are integrated to the cylindrical test block to measure friction torque occurred between the seal and shaft. The signals received from the force transducer are transmitted to a data acquisition system. The shaft was machined from stainless steel with hardness HRC30 and average surface roughness *Ra* = 0.5 µm.

For the experiments, custom-made radial lip seals are manufactured by SKF. The cross sectional views of seals are shown in Figure 2.

Thermoplastic polyurethane (TPU) and its two different versions; hydrolysis resistant thermoplastic polyurethane (H-TPU) and self-lubricated thermoplastic polyurethane (S-TPU) are selected as the elastomeric material.

Polyurethanes are thermoplastic elastomers which demonstrate the characteristics of elastomers over a wide temperature range and, in addition have the processing behaviour of thermoplastics. H-TPU combines the engineering properties of TPU with a high resistance to hydrolysis which is otherwise rarely found in polyurethanes. S-TPU has been optimized with regard to the tribological characteristics friction and wear by the addition of a synergetic combination of solid lubricants.

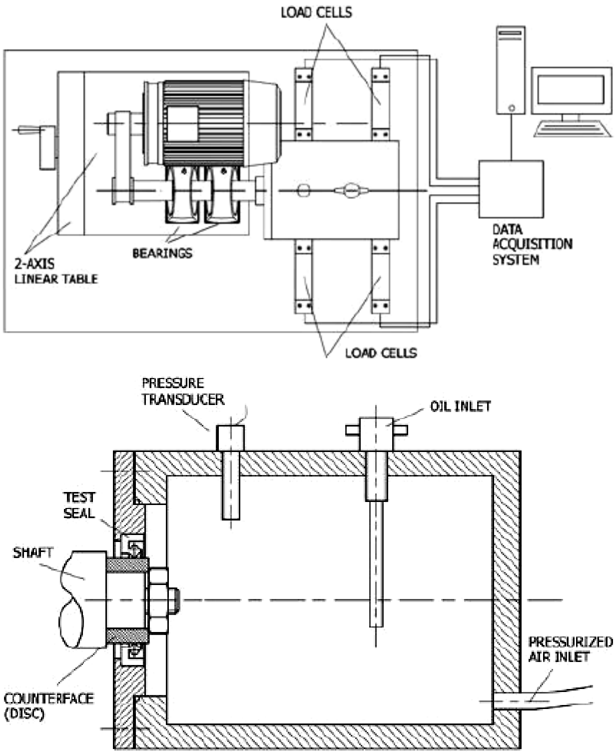

Figure 1. Schematic view of test system and test block

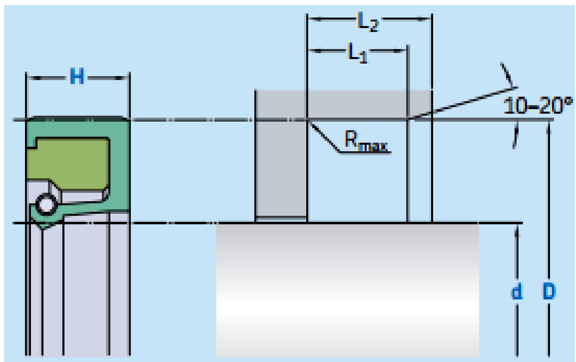

Figure 2. Cross-sectional views of test seals

Instead of standard inner diameters, custom-made radial lip seal samples were ordered. Therefore three different inner diameters (40, 39.80 and 39.60 mm) are selected for each elastomeric materials. Two groups of experiments were made and 27 samples were tested at 1, 3 and 5 m/s speeds. For the first group of experiments, the seals were tested under 0.5 and 0.3 bar for a short period. During the first group of experiments, the frictional torque values were measured and compared for different inner diameters. The effect of speed, pressure, material and interference were investigated. For the second group of experiments, the seals were tested for 10,000 meter sliding distance. The system pressure is selected to be 0.3 bar during tests. Throughout the second group of experiments, oil leakage observation and torque measurement were made. The effect of material and interference for relatively long sliding distances were investigated.

3. TEST RESULTS AND DISCUSSION

In Figure 3, the variation of frictional torque with sliding speed is given for TPU seals under 0.5 and 0.3 bar system pressure respectively. As expected, minimum interference gives minimum frictional torques. But, at relatively high pressure and speeds, the amount of interference does not effect frictional torques remarkably. It can be seen that frictional torque increases as the shaft speed increases. When the effect of interference is examined, it is observed that friction torque also increases as the interference is increased. There is not a significant difference between the friction torque results of TPU seals for 40 and 39.80 mm inner diameters at 1 m/s speed. On the other hand, the friction torque results of TPU seals for 39.80 and 39.60 mm inner diameters are close to each other at 3 and 5 m/s speed and under 0.5 bar pressure. However this result is not observed under 0.3 bar pressure. When the graphics are compared to each other, it is seen that the friction torque values decreases as the pressure decreases.

In Figure 4, the variation of friction torque with sliding speed under 0.5 and 0.3 bar pressure can be seen for H-TPU seals. As seen on Figure 2, frictional torque increases as the shaft speed increases. However, pressure drop from 0.5 bar to 0.3 bar does not affect friction torque values significantly. The friction torque values of H-TPU seals with 40 and 39.80 mm inner diameters are lower than the friction torque results of 39.60 mm H-TPU seals under 0.5 and 0.3 bar pressure. It is observed that the friction torque results of 40 and 39.80 mm H-TPU seals are close to each other.

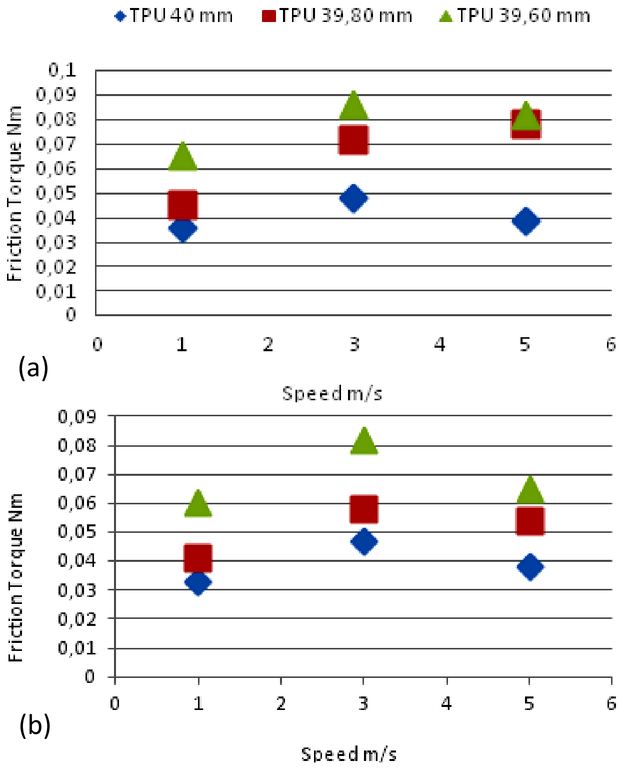

Figure 3. The variation of frictional torque of TPU seals with respect to sliding speed: (a) p = 0.5 bar and (b) p = 0.3 bar

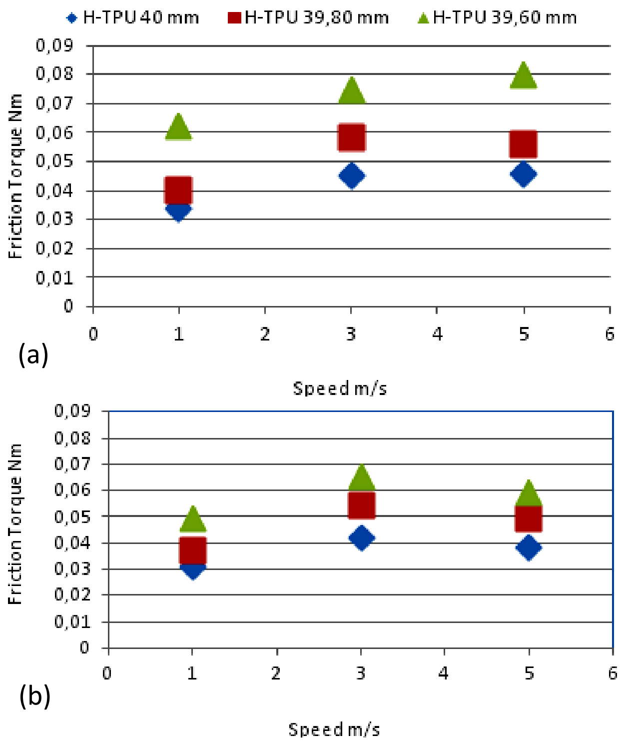

Figure 4. The variation of frictional torque of H-TPU seals with respect to sliding speed: (a) p = 0.5 bar and (b) p = 0.3 bar

The Figure 5 shows the variation of friction torque with sliding speed for S-TPU seals under 0.5 and 0.3 bar. It can be seen that frictional torque increases as the shaft speed increases as in the case of H-TPU. On the other hand effect of pressure on the friction torque results is too low and results are very close to each other for 0.5 and 0.3 bar inner pressure. The frictional torque values of 39.60 mm inner diameter S-TPU seals are higher than the friction torque values of 40 and 39.80 mm inner diameter S-TPU seals at 1 m/s. Unlike the Figure 2, the friction torque of S-TPU seals are the highest for 39.80 mm inner diameter at 3 and 5 m/s.

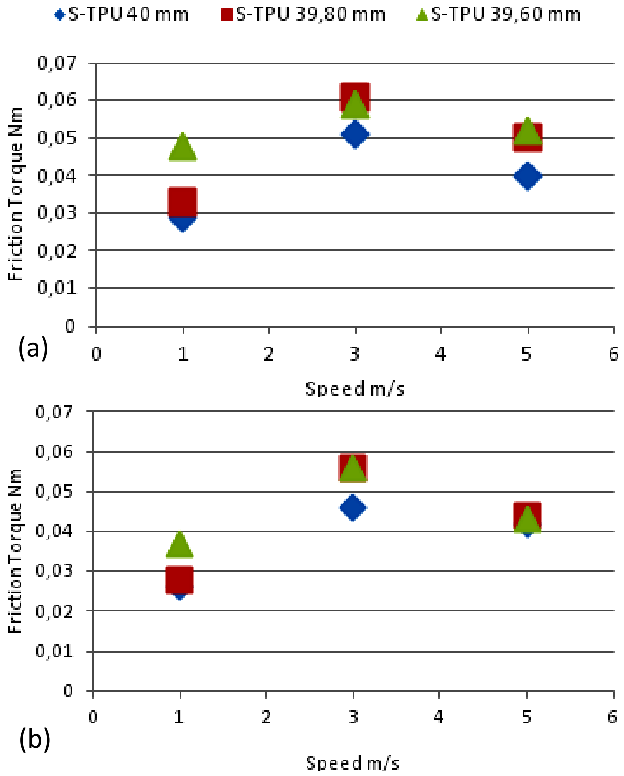

Figure 5. The variation of frictional torque of S-TPU seals with respect to sliding speed: (a) p = 0.5 bar and (b) p = 0.3 bar

The comparison of friction torque results of TPU, H-TPU, S-TPU seals for 40 mm inner diameters (practically zero interference) under 0.5 and 0.3 bar pressure can be seen in Figure 6. The friction torque results of S-TPU seals are lower at 1 m/s. However, a significant difference between the friction torque results is not observed.

The comparison of friction torque results of TPU, H-TPU, S-TPU seals for 39.80 mm inner diameters under 0.5 and 0.3 bar pressure can be seen in Figure 7. There is not a remarkable difference between friction torque results of seals. S-TPU seals give the lowest friction torque at 1 and 5m/s speed.

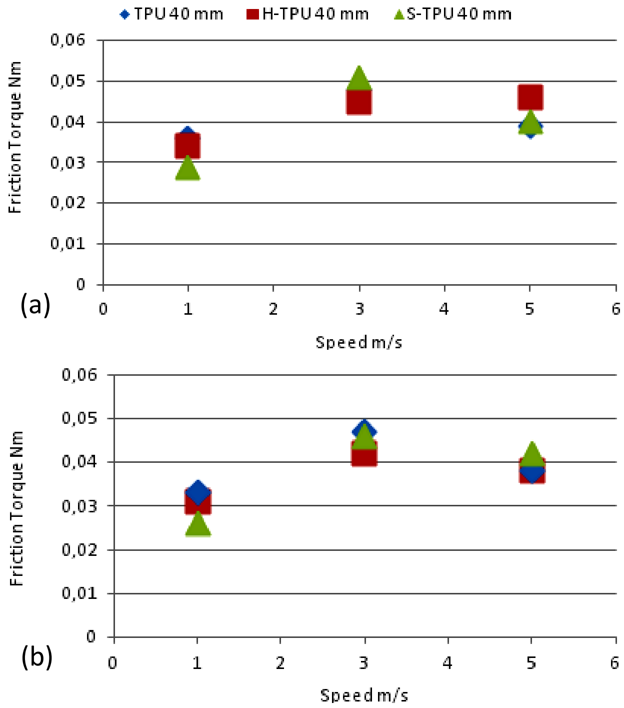

Figure 6. The friction torque results of TPU, H-TPU, S-TPU seals for 40 mm inner diameters: (a) p = 0.5 bar and (b) p = 0.3 bar

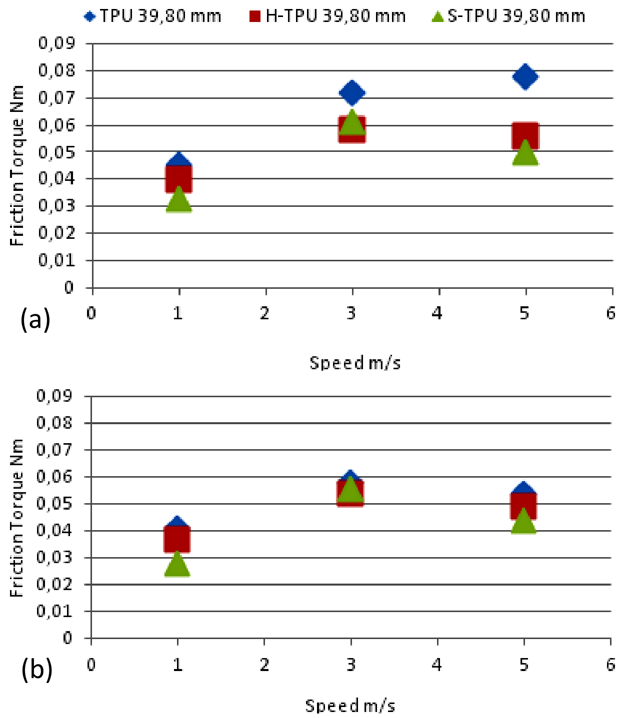

Figure 7. The friction torque results of TPU, H-TPU, S-TPU seals for 39.80 mm inner diameters: (a) p = 0.5 bar and (b) p = 0.3 bar

The comparison of friction torque values of TPU, H-TPU, S-TPU seals for 39.60 mm inner diameters under 0.5 and 0.3 bar pressure can be seen in Figure 8. The friction torque results of S-TPU seals are lower at all speeds. As shown in the Figure 8, this time additives in S-TPU material affect the results positively. The highest torque values are observed for TPU seals for 39.60 mm inner diameter. Under 0.5 bar pressure, the friction torque results of TPU and H-TPU seals are very close to each other.

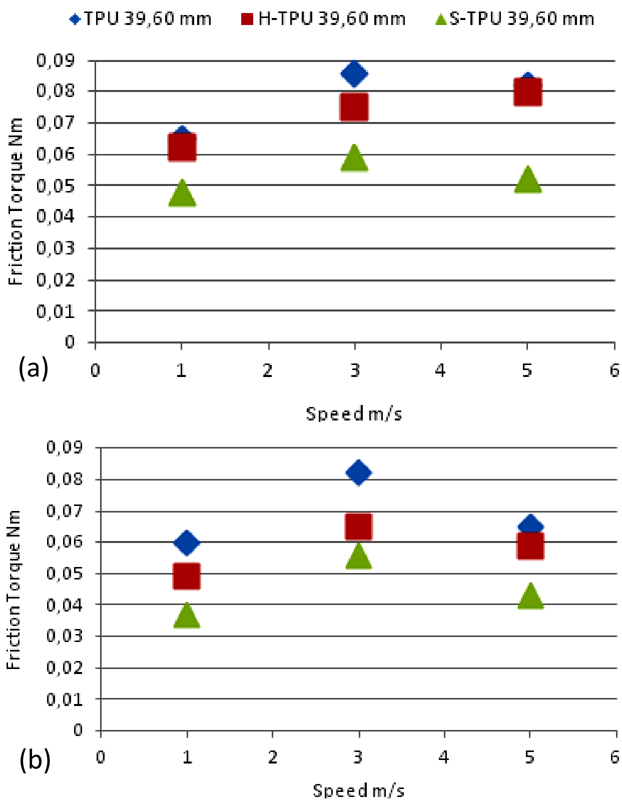

Figure 8. The friction torque results of TPU, H-TPU, S-TPU seals for 39.60 mm inner diameters: (a) p = 0.5 bar and (b) p = 0.3 bar

In the Figure 9, the variations of frictional torque with respect to sliding distance for TPU seals are shown for 1, 3 and 5 m/s sliding speeds respectively. A significant effect of interference is not observed at 1 m/s. However, together with an increase on the speed, interference affects the friction torque levels more remarkably. At 3 m/s speed, the friction torque level of 39.60 mm inner diameter TPU seal (the highest interference) is remarkably higher. At 5 m/s speed, the friction torque is observed to be highest for 39.80 mm inner diameter TPU seal and lowest for 40 mm inner diameter TPU seal.

In the Figure 10, the variations of frictional torque with respect to sliding distance for H-TPU seals are shown. At 1 m/s speed, the interference difference between 40 and 39.80 mm inner diameter H-TPU seals does not affect the level of friction torque remarkably.

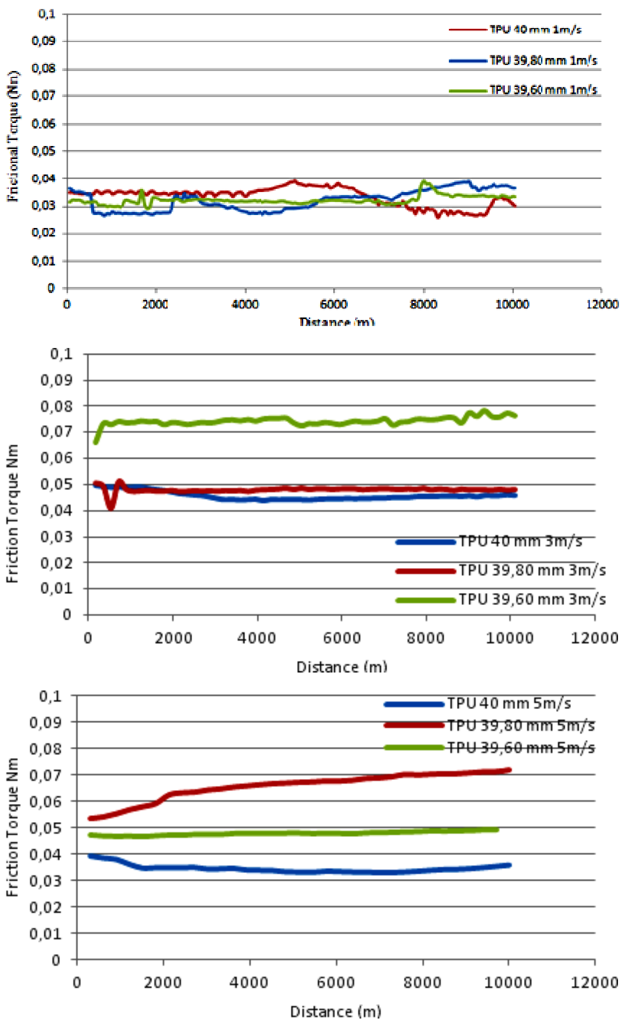

Figure 9. The variation of frictional torque with respect to distance for TPU seals

However a significant effect of interference is observed for 39.60 mm inner diameter TPU seal. At 3 m/s speed, the friction torque level of 39.80 mm inner diameter H-TPU seal is remarkably higher. At 5 m/s speed, the friction torque levels are observed to be close to each other.

The Figure 11, shows a plot of friction torque changing with distance for S-TPU seals with three different inner diameters. A significant effect of interference is not observed at 1 and 3 m/s speeds. Also, increasing the interference does not affect the friction torque results up to 3000 m sliding distance at a speed of 5 m/s. After that, friction torque increases with distance for 39.80 mm inner diameter S-TPU seal.

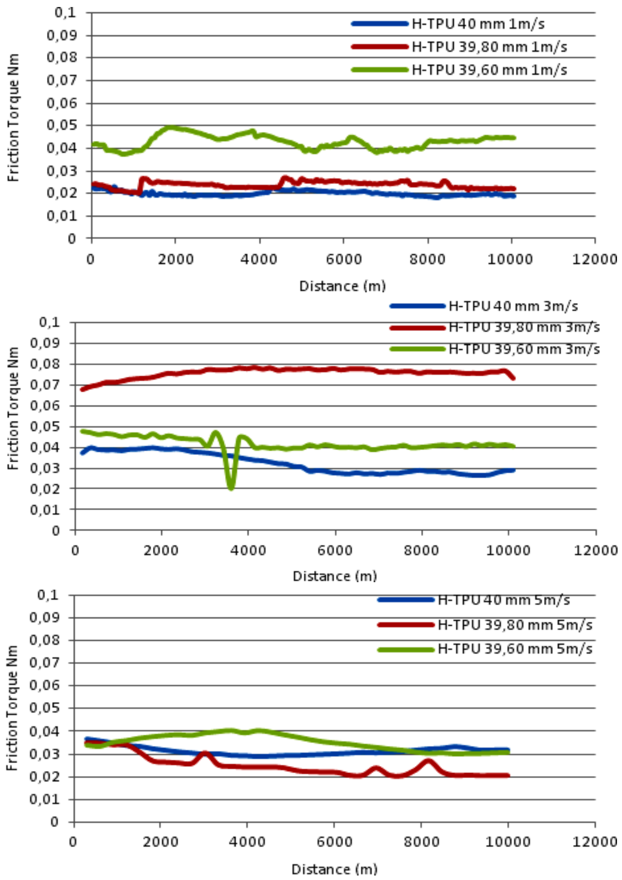

Figure 10. The variation of frictional torque with respect to distance for H-TPU seals

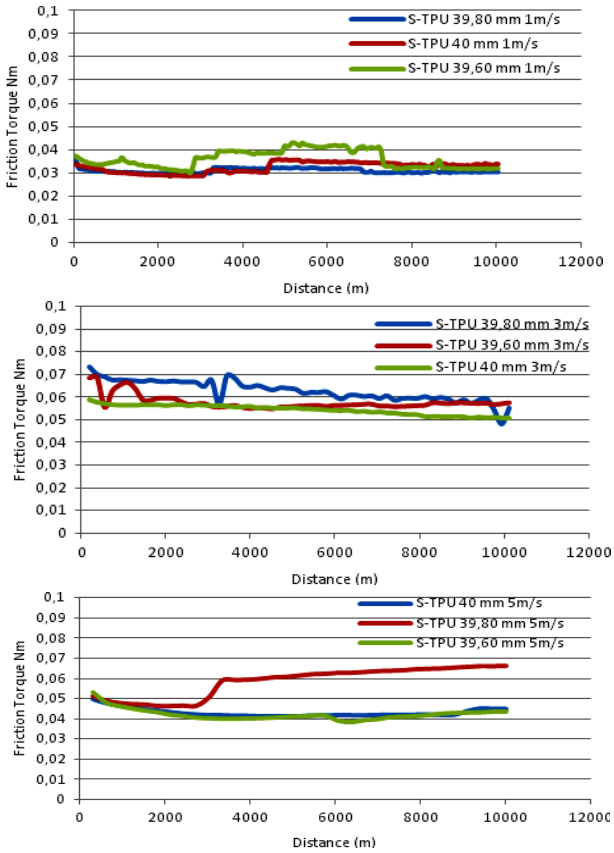

Figure 11. The variation of frictional torque with respect to distance for S-TPU seals

The comparison of friction torque of TPU, H-TPU, S-TPU seals at 1 m/s sliding speed for different interference values are shown in Figure 12. It is observed that the friction torque levels of seals are close to each other for the same interference. Despite the fact that S-TPU has an optimized tribological characteristics for friction and wear, its friction torque values are not remarkably lower since additives of elastomer may affect negatively the friction torque values of the seal.

The comparison of friction torque of TPU, H-TPU, S-TPU seals at 3 m/s are shown in Figure 13. In contrast to Figure 12, more significant differences between friction torque levels are observed. H-TPU seals gives the lowest friction results for the 40 and 39.60 mm inner diameter. On the other hand, the friction torque level of H-TPU seal is the highest for 39.80 mm inner diameter. It is observed that friction torque levels are close to each other for 40 and 39.80 mm inner diameter TPU and H-TPU seals.

The comparison of friction torques of TPU, H-TPU, S-TPU seals at 5 m/s for different

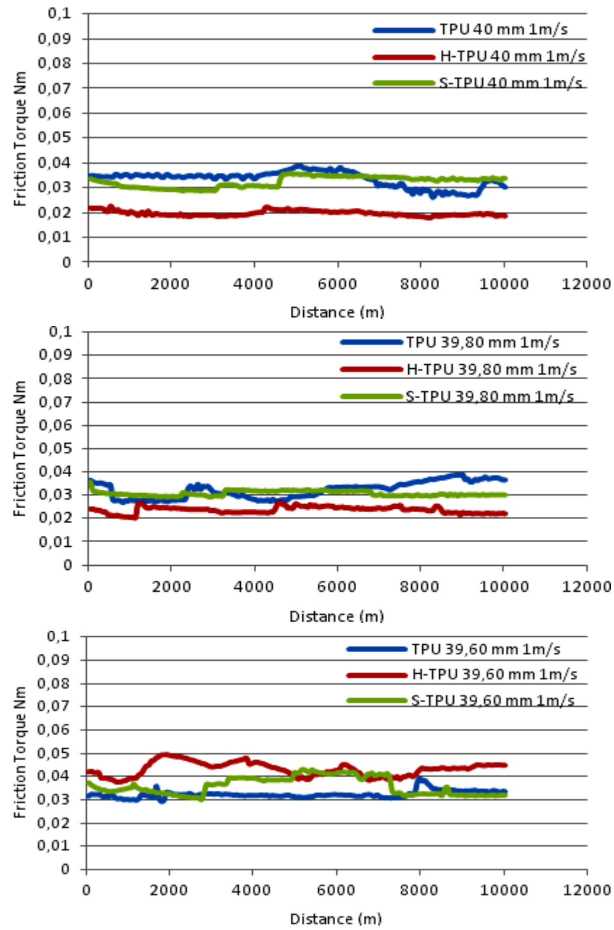

Figure 12. The comparison of friction torque of TPU, H-TPU, S-TPU seals at 1 m/s speed

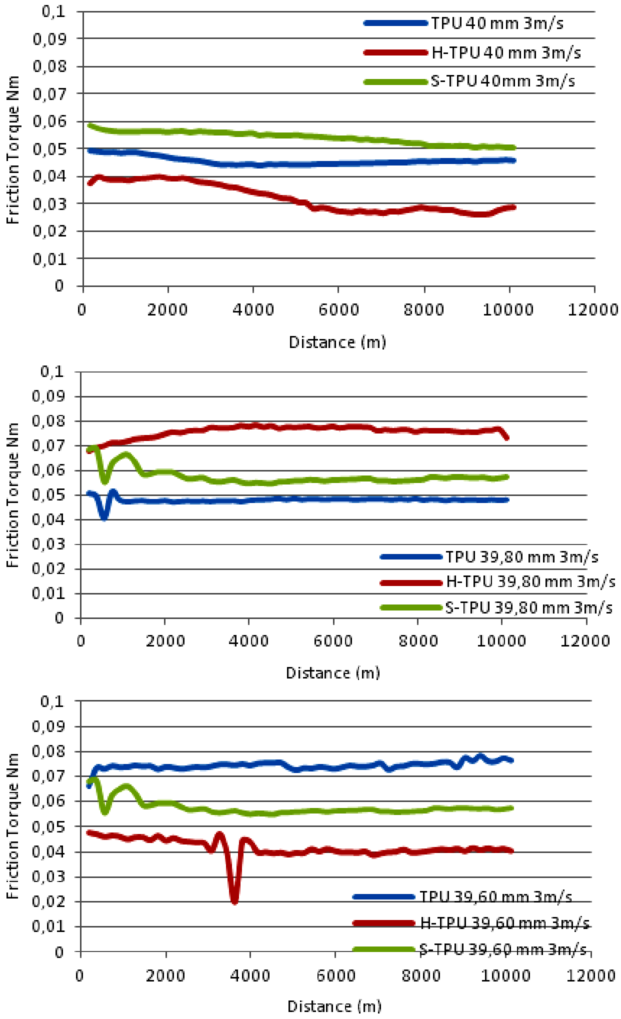

Figure 13. The comparison of friction torque of TPU, H-TPU, S-TPU seals at 3 m/s speed

interference values are shown in Figure 14. The frictional torque results of seals are close to each other for inner diameters 40 and 39.60 mm. Frictional torque levels of H-TPU seals are the lowest for all three inner diameters. Especially, the friction torque level of H-TPU is remarkably lower than the friction torque levels of TPU and S-TPU seals after 3000 m distance for the inner diameter 39.80 mm.

4. CONCLUSION

Regarding to all these experiments, the following conclusions can be drawn from the present study:

- As expected, the friction torque values of TPU, H-TPU and S-TPU seals generally increases as the interference increases.
- There is not a significant effect of interference on friction torque results at 1 m/s speed.
- The frictional torques obtained for 3 m/s and 5 m/s speeds for the seals with 40 and 39.80 mm inner diameter are significantly lower than the friction torque values of the seals with 39.60 mm inner diameter.
- On contrary to the literature, the additives in S-TPU seal do not affect the friction torque values positively and mostly causes the S-TPU seal to give higher friction torque values than TPU and H-TPU.
- Leakage is not observed during experiments.
- As expected, It has been observed that contact surface temperatures of the seals rises as the interference increases.
- Changing the pressure from 0.5 bar to 0.3 does not affect the friction torque values remarkably.
- A significant wear is not observed on the contact surface of seals at macro level.

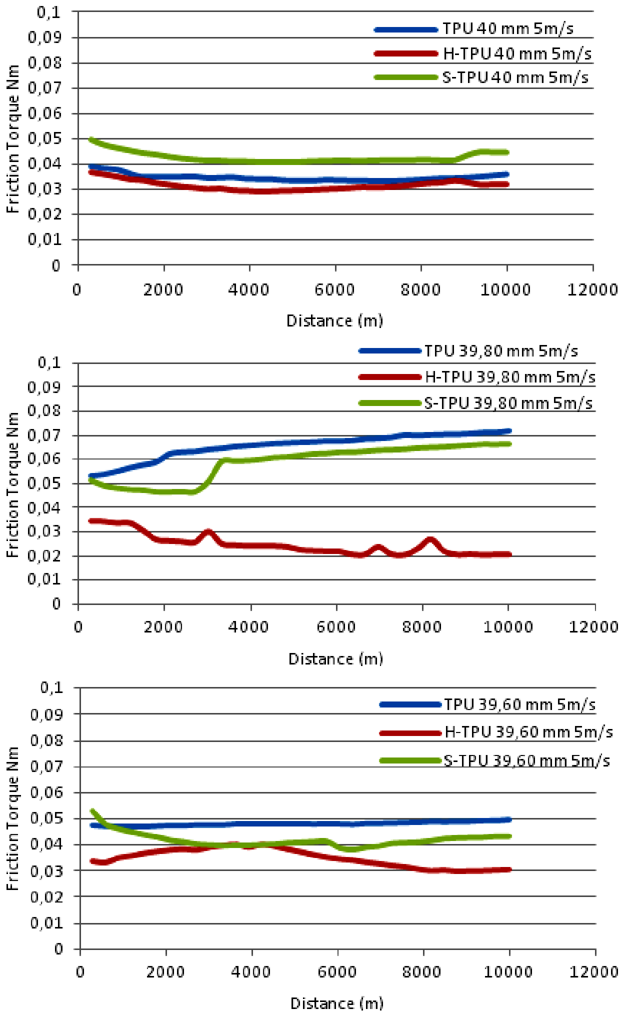

Figure 14. The comparison of friction torque of TPU, H-TPU, S-TPU seals at 5 m/s speed

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