Influence of Temperature on PA 6-steel Contacts in the Presence of an Ionic Liquid Lubricant

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1. INTRODUCTION

Room-temperature ionic liquids (ILs) are salts with a melting point lower than room temperature and are called green solvents because they have properties such as:

- Non-flammability,
- Negligible volatility, and
- High thermal stability.

The high thermal stability range (from -74 ºC to 370 ºC in our case) of ILs makes them suitable candidates as high temperature and extreme temperature lubricants. In this work we present the mechanical and tribological properties of polyamide 6-IL dispersion (PA 6+3wt.% IL) under variable load and temperature conditions, against AISI 52100 steel or AISI 316L stainless steel.

Figure 1. IL: 1-hexyl, 3-methyl imidazolium hexafluorophosphate

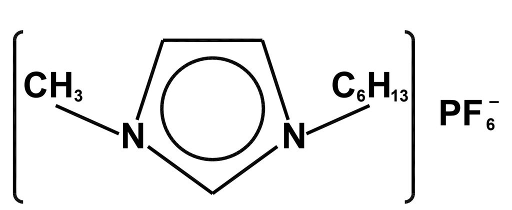
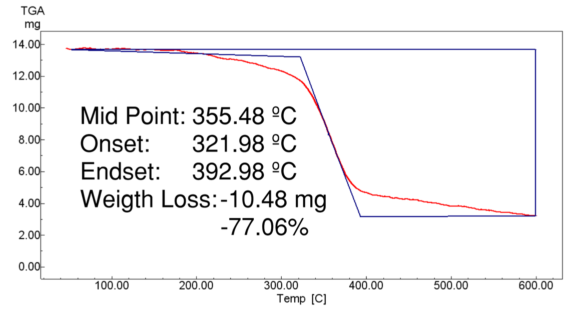


Figure 2. TGA Analysis of IL in N_2 atmosphere



2. PREPARATION AND PROPERTIES OF PA 6+IL DISPERSIONS

2.1. EXTRUSION

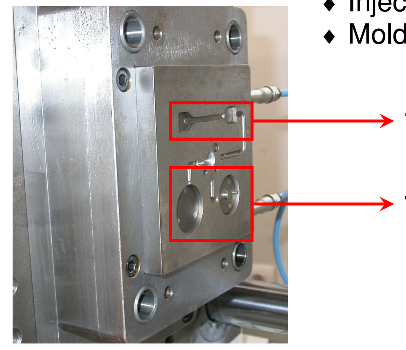
- Extrusion temperature: 270 ºC

Figure 3. Extrusion equipment: LEISTRITZ ZSE18 HP-400

2.2. INJECTION MOLDING

Figure 4. Injection machine: DEU 250H55 mini VP

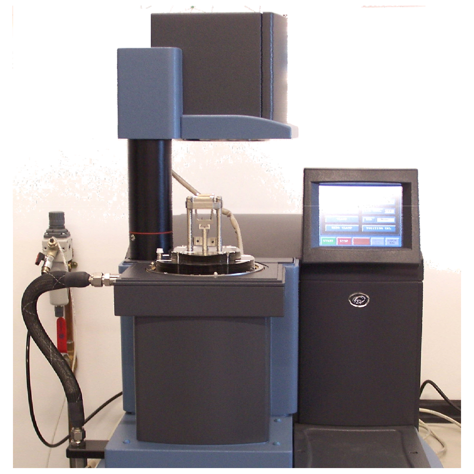
Figure 5. Detail of the mold cavities



- Injection temperature: 265 ºC
- Injection pressure: 96.4 MPa
- Mold temperature: 90 ºC

2.3. DYNAMIC MECHANICAL ANALYSIS (DMA)

Figure 6. DMA equipment: TA Q800 DMA



- Tests Configuration: Single cantilever

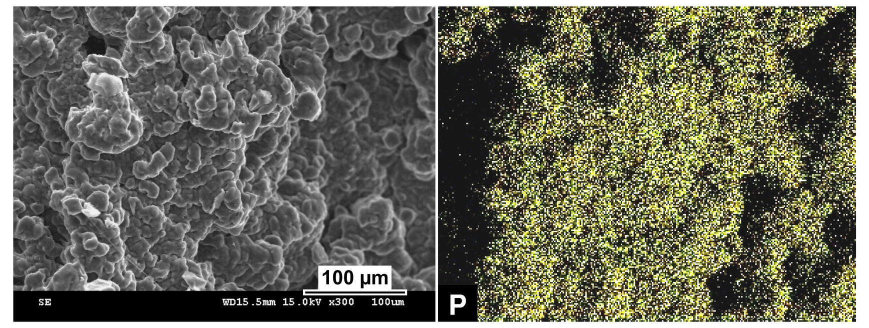
Determination of the temperature variation of:

- Loss Modulus (a measure of the stress dissipated as heat)
- Storage Modulus (stress stored as mechanical energy)
- Tan δ (Loss Modulus/Storage Modulus)

2.4. MICROSTRUCTURE OF THE BLEND

An homogeneous dispersion of IL into the PA 6 matrix is obtained, as can be seen in the fracture surface mapping (Figure 7).

Figure 7. SEM micrograph and EDS elemental P mapping



2.5. HARDNESS AND TENSILE PROPERTIES AT ROOM TEMPERATURE

PA 6 + 3% IL shows a similar hardness to that of neat PA 6, with a higher elongation at break and a slight reduction in resistance (Table 1).

Table 1. Mechanical properties of the specimens. Standard deviations in brackets

Material	Hardness (Shore D)	Tensile Strength (MPa)	Elongation at break (%)
PA 6	71.7 (0.96)	69.5 (3.60)	191.8 (7.80)
PA 6 + 3wt.% IL	71.0 (0.41)	60.8 (5.30)	237.8 (15.20)

Figure 8. PA 6 specimens before and after the tensile tests

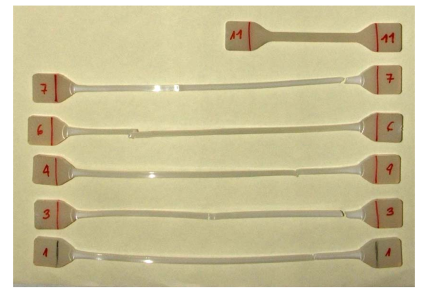
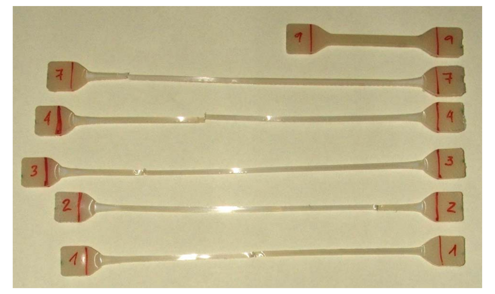


Figure 9. PA 6 + 3wt.% IL specimens before and after the tensile tests



2.6. DYNAMIC MECHANICAL PROPERTIES

Temperature values selected for tribological tests are those at which PA 6 and PA 6+3% IL show the same moduli relationship:-35, 25 y 67 ºC (Figure 12).

Figure 10. Loss Modulus vs Temperature

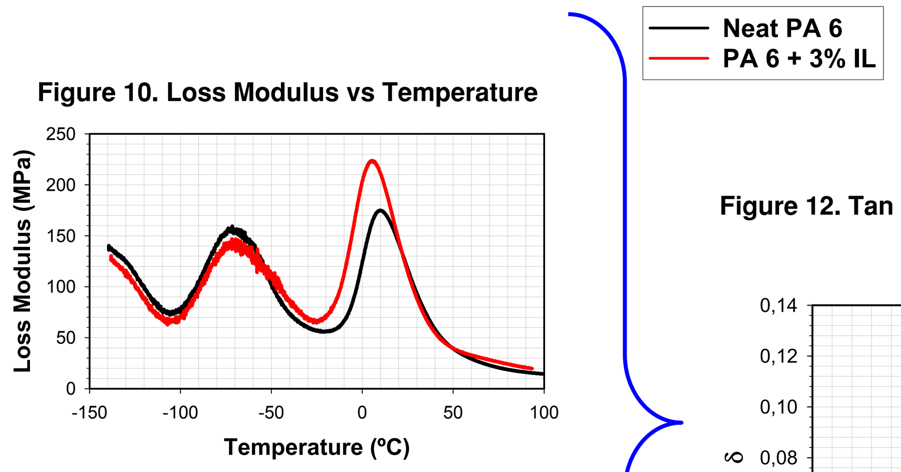


Figure 11. Storage Modulus vs Temperature

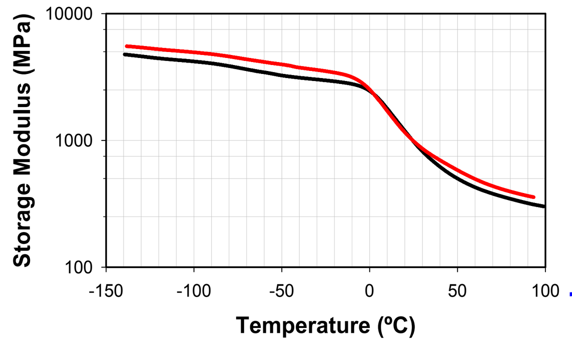
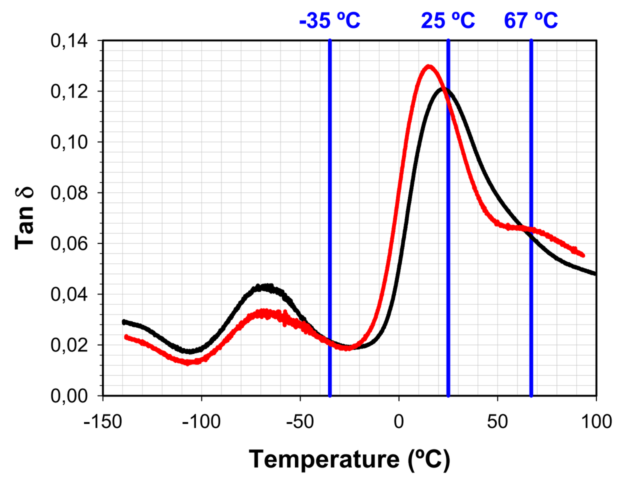


Figure 12. Tan δ (Loss Modulus/Storage Modulus) vs Temperature



3. TRIBOLOGICAL RESULTS

3.1. TEST CONFIGURATION

Figure 13. Test configuration at low temperature (-35 ºC)

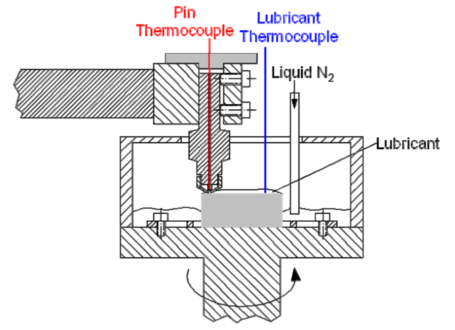
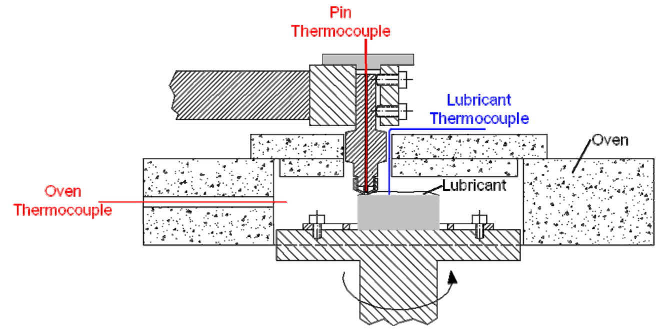


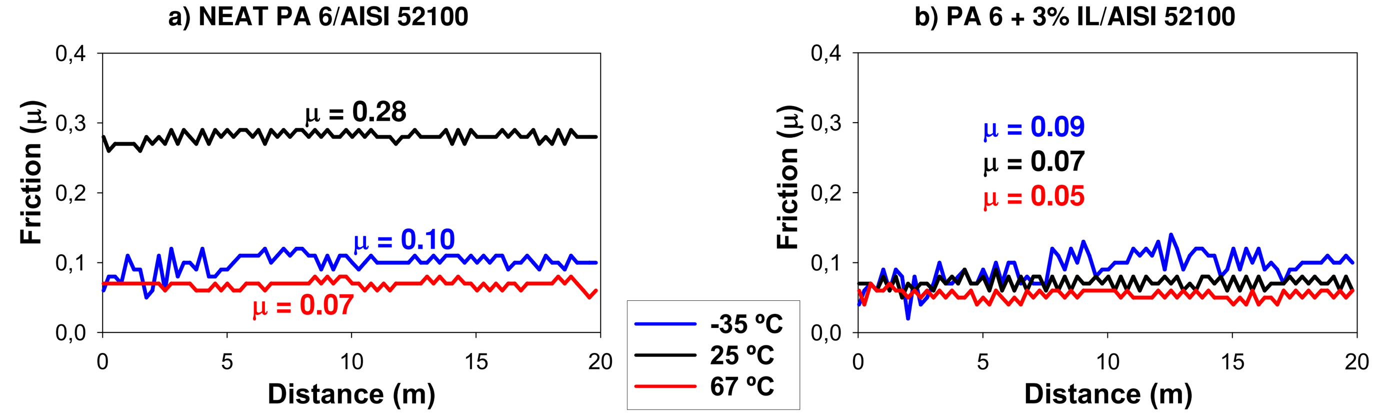
Figure 14. Test configuration at high temperature (67 ºC)



3.2. VARIABLE TEMPERATURE DRY FRICTION vs DISTANCE RECORDS (2.45 N; 0.10 ms^{-1})

- Neat PA 6 shows a friction decrease both at high and low temperature with respect to room temperature, due to thermal softening and low temperature hardening, respectively (Figure 15.a).
- PA 6 + 3% IL always shows low friction, with no significant friction variations with temperature (Figure 15.b).

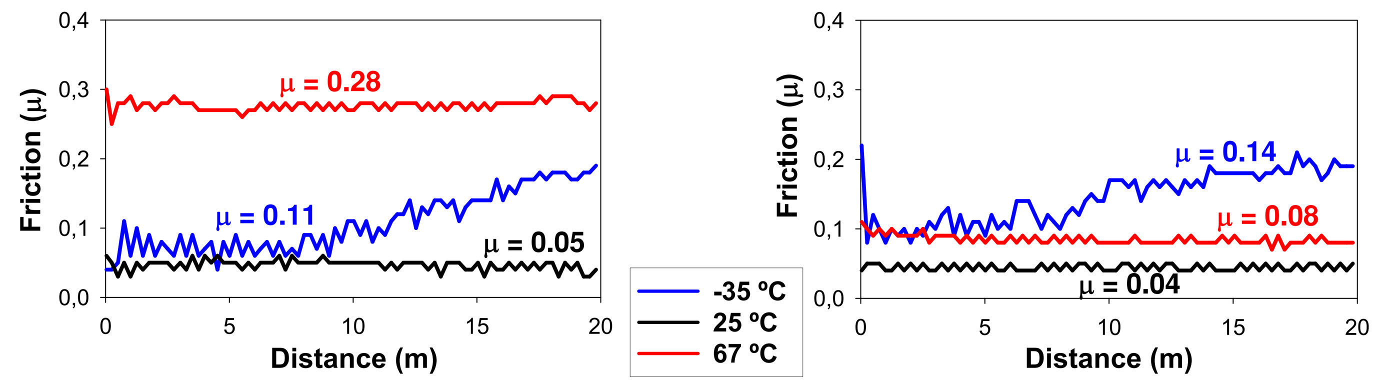
Figure 15. Dry friction vs distance at variable temperature



3.3. VARIABLE TEMPERATURE IL-LUBRICATED FRICTION vs DISTANCE RECORDS (2.45 N; 0.10 ms^{-1})

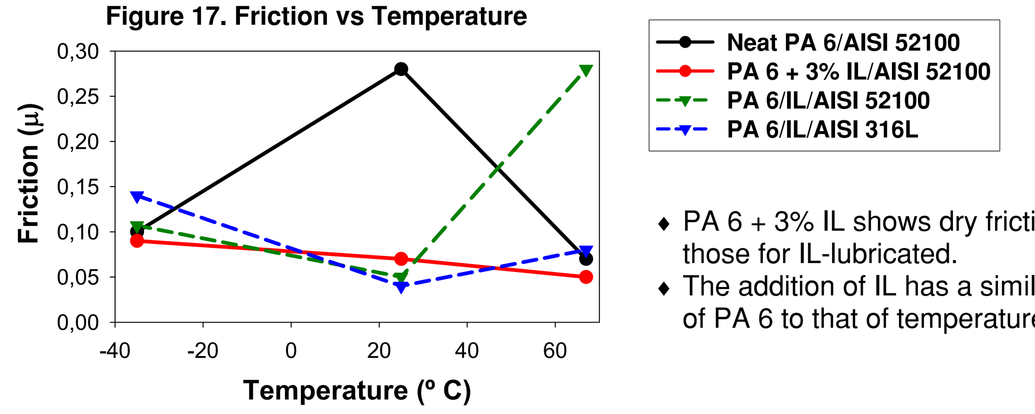
- IL-lubricated friction against AISI 52100 steel increases at high temperature due to tribocorrosion interactions (Figure 16.a).
- In absence of tribocorrosion, for AISI 316L stainless steel, this friction increase at high temperature is not observed (Figure 16.b).

Figure 16. Friction vs distance at variable temperature



3.4. MEAN FRICTION RESULTS

Figure 17. Friction vs Temperature



- PA 6 + 3% IL shows dry friction similar or lower than those for IL-lubricated.
- The addition of IL has a similar effect on the friction of PA 6 to that of temperature changes.

3.5. IL-AISI 52100 TRIBOCHEMICAL INTERACTIONS

Steel balls show a higher proportion of phosphorus-rich deposits on the surface after external lubrication tests with IL at 67 ºC (Figure 19) with respect to room temperature (Figure 18), corresponding with the high friction coefficient observed under these conditions (Figure 17).

Figure 18. AISI 52100 steel ball after lubrication with IL at 25 ºC

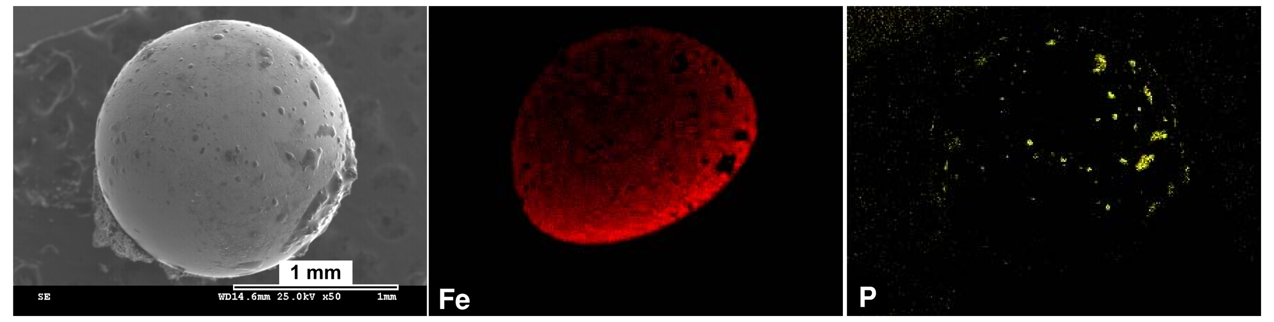
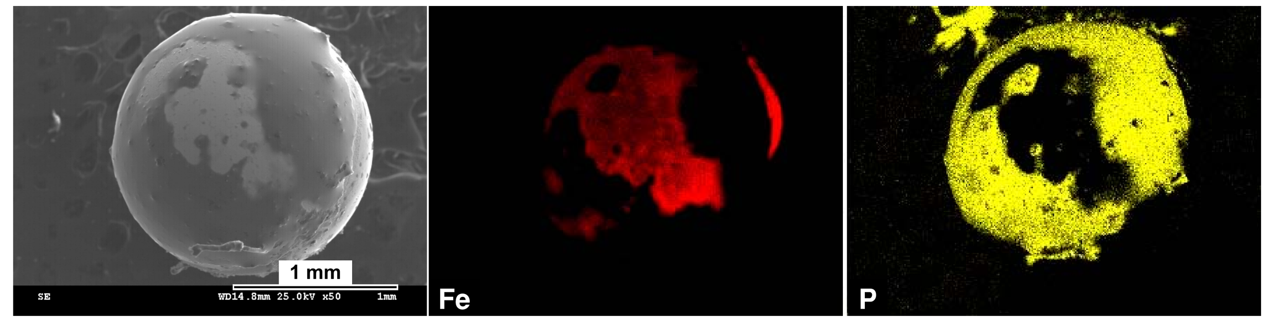


Figure 19. AISI 52100 steel ball after lubrication with IL at 67 ºC



3.6. DRY WEAR MECHANISMS AS A FUNCTION OF NORMAL APPLIED LOAD

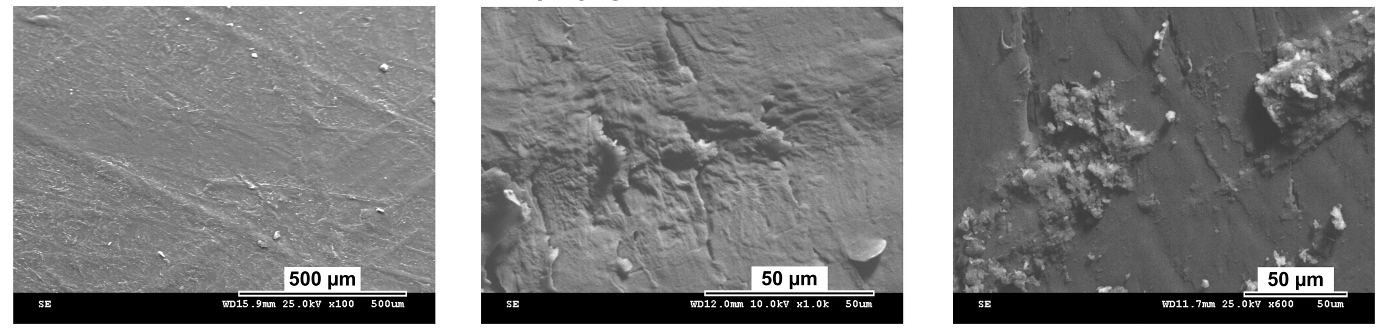
- Under low load (2.45 N) negligible wear and no crack propagation is observed (Figure 20.a).
- Under high load (7.35 N) severe wear mechanism is observed with crack propagation (Figure 20.b) and wear debris formation (Figure 20.c).

Figure 20. SEM Micrographs of dry wear tracks on PA6 + 3% IL

Figure 20.a. Negligible wear under 2.45 N

Figure 20.b. Transversal crack propagation under 7.35 N

Figure 20.c. Wear debris under 7.35 N



4. CONCLUSIONS

- **Dynamic mechanical analysis shows the same moduli relationship for PA 6 + 3% IL and PA 6 at –35, 25 and 67ºC.**
- **Neat PA 6 shows a friction decrease both at low (-35ºC) and high (67ºC) temperature with respect to room temperature.**
- **PA 6 + 3% IL shows low constant friction values, under the whole range of temperatures.**
- **PA 6 + 3% IL always shows lower friction and wear rate values than PA 6, under increasing normal load.**
- **The improved tribological performance of PA 6 + 3% IL is attributed to the formation of stable adsorbed layers of the highly polar IL molecules on the steel surface.**
- **Low friction values are obtained when IL is used as external lubricant of PA6-stainless steel contacts.**
- **The results presented here open the possibility of developing new polymer-ionic liquid dispersions with high tribological performance under a wide temperature range.**

ACKNOWLEDGEMENTS

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