VALIDATION OF DESIGN SOLUTIONS AND MATERIALS FOR A HIGH PERFORMANCE BEARING CAGE

Aleida Lostalé[(a)], Isabel Clavería[(a)], Ángel Fernández[(a)], Manuel Muniesa[(a)], Carlos Javierre[(a)], Daniel Elduque[(a)], Sergio Santodomingo[(a)]

[(a)]University of Zaragoza I+

[(a)]isabel.claveria@unizar.es,

ABSTRACT
Bearings are one of the most used components in mechanical engineering. One element in the bearing assembly having a great influence in its performance is the cage. Cages work mainly under friction and inertia loads, so the selection of a proper material with low density and good mechanical and friction properties is essential. This paper analyzes the injection molding feasibility of different polymeric matrix to be used in composite materials for cage design. Alternative geometrical design of the cage optimized for lubrication purposes will be also analyzed in order to make sure its manufacturing feasibility. Results conclude that polyamide, mechanically improved with glass fiber, is the best option for polymeric matrix regarding injection molding process. On the other hand new cage geometry requires some modifications in injection molding parameters to meet process requirements.

Keywords: bearing, cage, mechanical design, injection molding.

1. INTRODUCTION

Bearings are the most used components in mechanical engineering to allow relative rotational motion between two concentric elements. Conical bearings are one of the most widespread bearings because of their stiffness, load capacity, rotation speed and equilibrium between radial and axial load. One of the components of the conical bearing assembly is the cage, which have a great influence on the suitability of the bearing for a specific purpose. Cages on bearings are required for keeping the rolling elements separated, for achieving a uniform distribution of the rolling elements, for guiding rolling elements to avoid sliding, and for retaining the rolling elements during assembly.

Cages usually have a passive role during bearing performance, and this study pretends them to become an active role thanks to the usage of new materials and new geometries.

Cages usually work under loads derived from friction and inertia (Kohar and Hreck 2016), as well as deformation due to pressure. Besides, the usage of lubricants and greases can affect chemically the cage material reducing its properties. That is why a proper selection of matrix materials for the cage and additives are strongly relevant to make sure the functionality of the bearing and improve its performance (Gunst Zabel Valle 2010).

New trends in cage design are focused on solid cages that are the most used for conical bearings and the most suitable for innovation. These cages combine in a very profitable way flexibility and resistance (Fang, Pugh, and Themudo 2007). If polymeric materials are used, the advantages of a serial manufacturing process like injection molding process can be combined with the good friction properties of some polymers. Injection molding process also allows to achieve an excellent surface quality to get in touch with the rollers. Another advantage of using polymers is their low density, minimizing the effect of inertia loads on the cage, which make them optimum for high speed and long term performances.

The most important limitations that solid cages have are two: high temperatures reached due to low conductivity of polymers under continuous work conditions, and ageing caused by some kind of lubricants on the polymer matrix.

New trends for high performance bearings are focused on new materials (Foster, Rosado, Brown et al. 2002), with low friction and high mechanical properties and high working temperature, new methods of lubrication for high temperatures and higher limits of speed-pressure (Ettefaghi 2013; Liu 2011; Huang 2011), new surface treatments for the rolling roads (Ciarsolo Fernández Ruiz de Gopegui Zubizarreta Abad Mariscal caretti Jiménez sánchez-López, 2014; Manier Ziegele Barriga, Goikoetxea Woydt, 2010) and new design of the components.

The goal of this research is to optimize cage geometry and material in order to obtain a more effective design for high performance purposes. Different cage geometries and materials will be analyzed from the point of view of mechanical and rheological behavior to meet the optimum design according to mechanical and manufacturing process requirements.

Regarding to geometry, the goal of this paper is validate new shape of the cage from the point of view of injection molding process, establishing strong and weak points regarding the original geometry. On the other hand, regarding to material, another aim of the paper is to analyze the mechanical and rheological behavior of different potential materials for the polymeric matrix of the cage.

2. METHODOLOGY

Two different geometrical models are going to be analyzed varying some geometrical features that could be relevant to get a better tribological performance as well as different materials. Figure 1 shows a basic geometry that is now being used in some applications. From this geometry, a modification in the size of rolling elements cells will be carried out to create an alternative model that could be tested from tribological point of view. Anyway, a rheological and mechanical analysis is before required to guarantee the feasibility of the component.

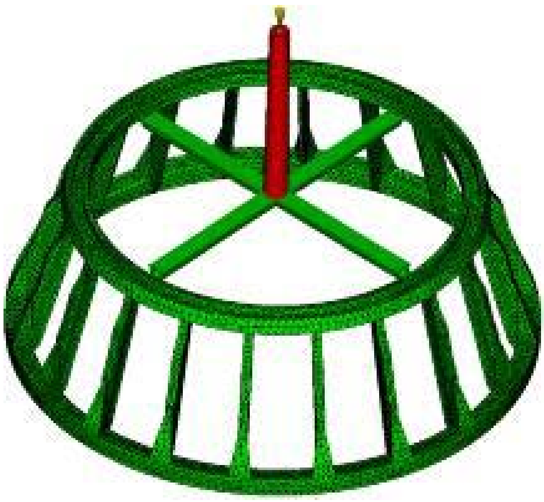


Figure 1: Basic model to analyze

Regarding to materials, different polymeric matrix have been analyzed. A first group of technical polymers including Polyamide 66 (PA66), Polyamide 46 (PA46), Polyacetal (POM) and Polytetrafluoethylene (PTFE) will be tested. On the other hand a set of high purpose polymers including Polieteretercetone (PEEK) and Polyeterimide (PEI) will be also tested in order to validate mechanical and rheological behavior.

A matrix of tests has been designed to compare rheological and mechanical behavior according to Table 1.

Table 1: Study cases

	Material	Geometry
M1	PA66	Basic
M2	PA46	Basic
M3	POM	Basic
M4	PEEK	Basic
M5	PTFE	Basic
M6	PEI	Basic
G1	PA66	Alternative
G2	PEEK	Alternative

For each of the study cases a rheological analysis evaluating their manufacturing feasibility by injection molding process will be carried out by means of software MOLDFLOW PLASTICS INSIGHT®. The methodology follows a flow+warp analysis including filling, packing and cooling stages of injection molding process as well a warpage calculation. Results related to both process feasibility such as melt front advancement, injection pressure and shear stress, and related to mechanical behavior such as deflection of the part will be discussed. These results are essential to determine the suitability of the material or design for bearing performance because the rolling elements must fit perfectly between the cage spaces to minimize friction between components.

3. RESULTS

3.1. Rheological analysis

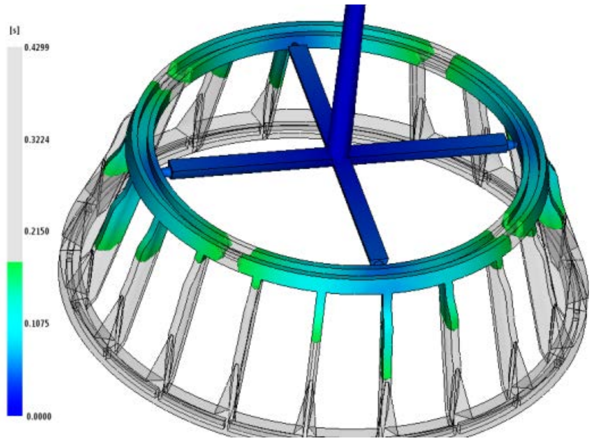


Figure 2: Melt front advancement at the beginning of injection time

Figure 2 shows melt front advancement result for M1 study case. It provides information about the proper flow pattern along part during injection time. This pattern is required to be both as uniform as possible and finishing filling at the same time all around the part contour. This fact can be seen on figure 3 for a total injection time of 0.5 seconds. It can be observed that flow near part entrance points goes further and this area of the part completes its filling slightly before. That is the reason why short filling times are considered in order not to let the first material freeze while the part completes the filling. Melt front advancement depends strongly on the injection point. As the feeding system remains the same for all the study cases this result is similar for all the materials and geometries tested.

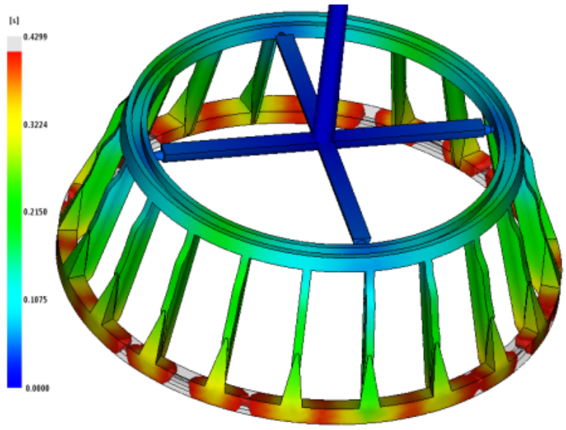


Figure 3: Melt front advancement at the end of injection time

One of the most important results to validate the feasibility of an injected part is maximum injection pressure reached at the end of filling stage when the whole cavity of the mold part is 99% completely filled. This pressure value has to do with part thickness, part flow length, material viscosity and flow rate. For this kind of geometry with short flow length values under 60 MPa are recommended. For the base cases analyzed M1 a maximum value of 25 MPa is obtained in figure 4. Pressure distribution at the end of filling is another parameter related to injection pressure to be taken into account. It should homogenous around the outer contour of the part, which indicates that the part has completed its filling at the same practically at the same time as described in Figure 4.

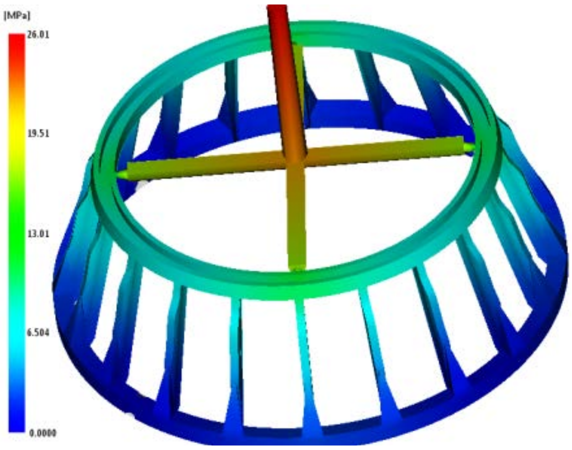
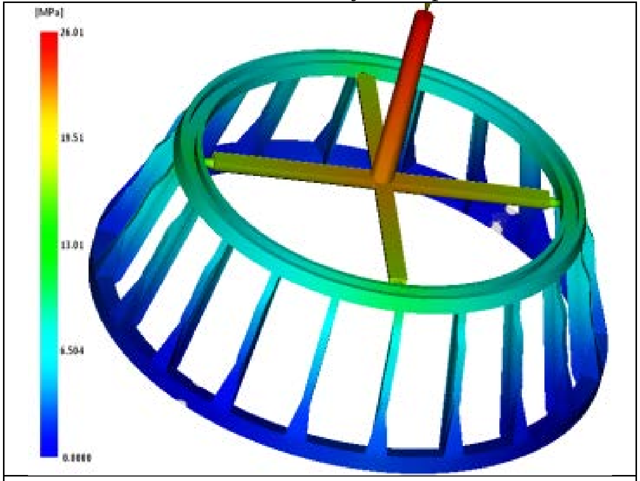
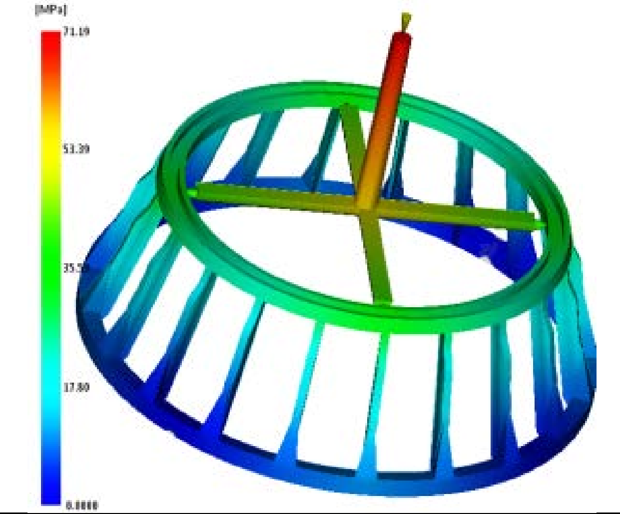
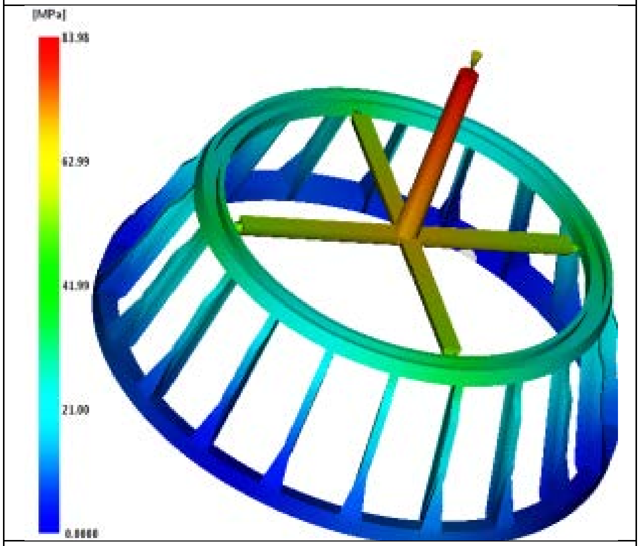
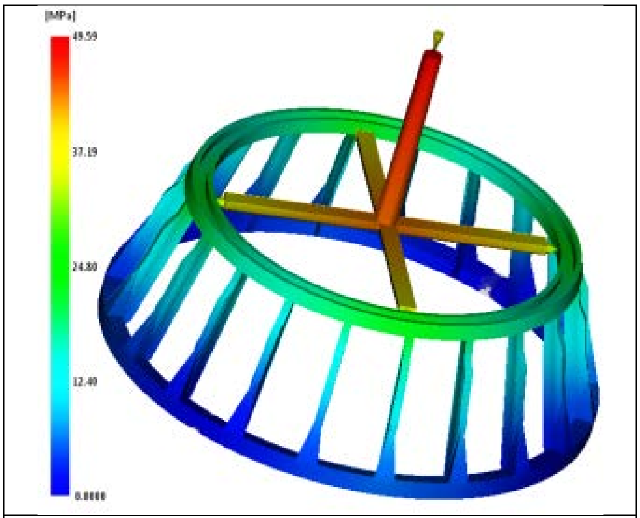


Figure 4: Maximum injection pressure and distribution for study case M1

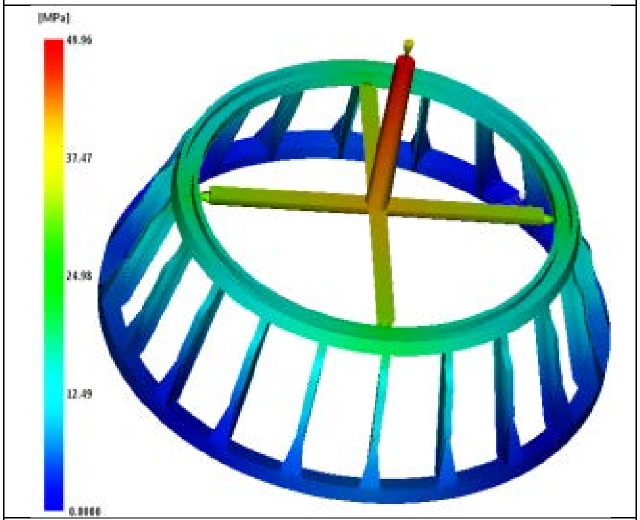
Table 2 shows pressure results of different material cases M1 to M6 analyzed. It can be observed that PEI, PTFE and POM require higher injection pressures above 60 MPa even over 100 MPa for PEI. It is mainly due to high viscosity values of theses material for the shear rates reached during injection molding. PEEK and PA46 reach medium values around 50 MPa that would be an adequate limit pressure for this kind of geometry, and finally PA66 reaches low pressure values under 30 MPa due to mainly its lower viscosity. Maximum injection pressures for alternative geometry are around 10% lower due to the higher thickness of the rolling elements cells walls that makes easier the flow.

Table 2: Maximum injection pressure

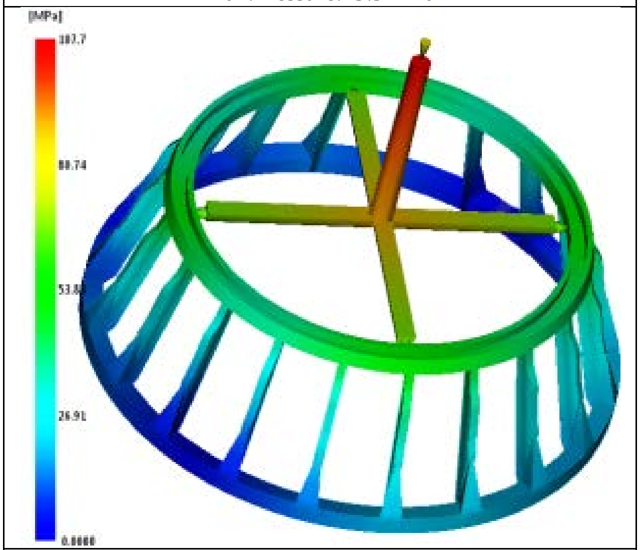

M1-(PA66) Max. Pressure: 26.8 MPa

M3-(POM) Max. Pressure: 71.1 MPa

M5-(PTFE) Max. Pressure: 83.9 MPa



M2-(PA46)
Max.Pressure: 49.5 MPa



M4-(PEEK)
Max.Pressure:49.9 MPa



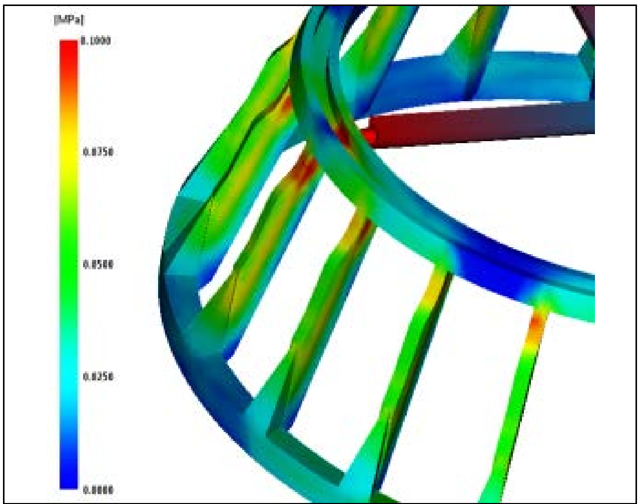
M6-(PEI)
Max. Pressure: 107.7 MPa

G2 (PEEK)
Max. Pressure: 37.9 MPa

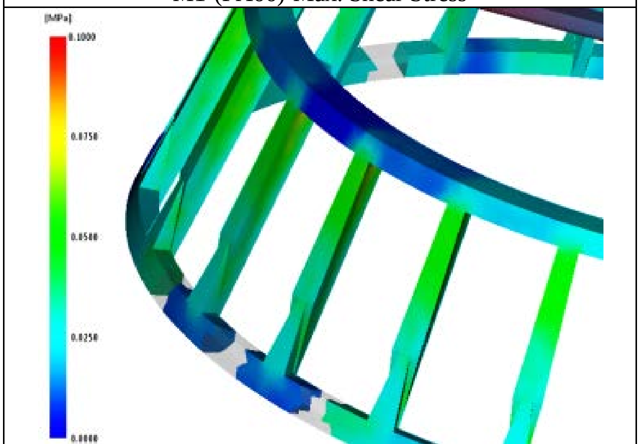
G1 (PA66)
Max. Pressure: 23.2 MPa

Shear stress is another result to be taken into account for this kind of components subjected during its working life to mechanical loads. Shear stress provides information about the residual stress that remains into the injected part due to manufacturing injection process. This residual stress will be added to the stresses generated by the external loads applied to the component. It is advisable to reduce to a minimum this stress, and, on the other hand to be confident about not to overpass maximum allowable shear stress values for different materials. Shear stress generated has to do mainly with maximum injection pressures reached and part thickness.

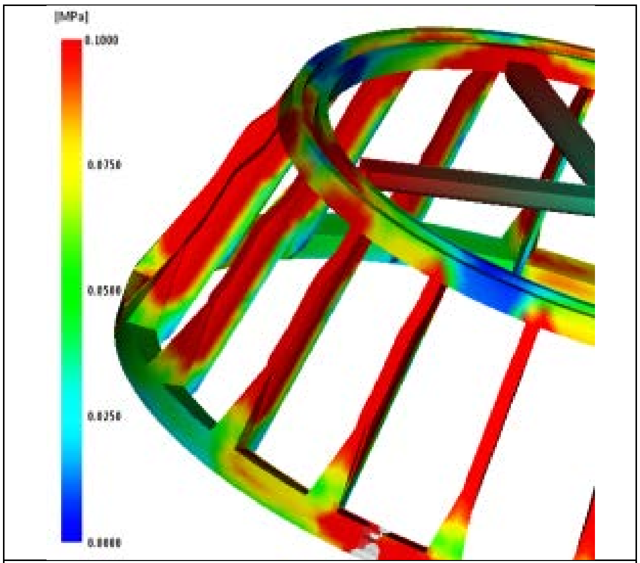
Figure 5 shows shear stress results for base geometry (M1, M4) and alternative geometry (G1, G2). All the results have been scaled to 0.1 MPa, therefore red areas indicate higher shear stress values. Study cases with base geometry (M1, M4) shows red areas with top stress values. These areas correspond to a change in the cross section thickness of the part, where it is more likely to appear shear stress problems. For alternative geometry (G1, G2), these areas have been softened with transition thickness areas to avoid abrupt changes in cross section of the part, which leads to lower shear stress values.



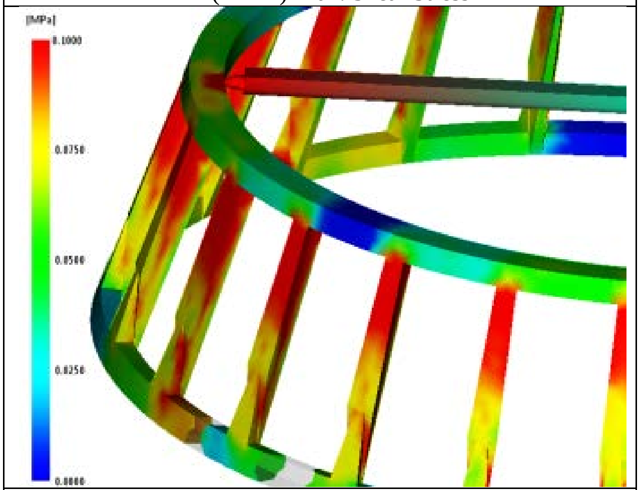
M1-(PA66)-Max. Shear Stress



G1-(PA66)-Max. Shear Stress



M4-(PEEK)-Max. Shear Stress



G2-(PEEK)-Max. Shear Stress

Figure 5: Shear stress for base geometry (M1, M4) and alternative geometry (G1, G2)

3.2. Mechanical analysis

Main purpose of the bearing cages is housing the rolling elements. To achieve an optimum performance of the bearing friction between rolling elements and the cage must be reduced at minimum. The way how injection process contributes to meet this requirement is finding the material, geometry and process conditions to obtain a post-molding deflection as low as possible to avoid undesirable additional friction between components.

Figure 6 shows qualitative results for cage deflection due to injection manufacturing process. From the graphical result can be observed that part tends to close radial and tangentially by reducing both outer and inner diameters and leaving less space for the rolling elements. Because of the same filling pattern obtained for all the study cases the deflection mechanism is the same for all the materials and geometries. In spite of it, different mechanical and shrinkage properties of the different materials maximum deflection values change according to values shown in table 3.

Higher deflections values are reached for PEEK and POM near 1 mm. Lower values are achieved for PTFE and PEI and medium values are obtained for PA66 and PA46. According to functionality tests, deflection values under 0.5 millimeters are allowed for the cage performance, so POM and PEEK would be discarded by this reason. Both PA66 and PA46 reach values next to the limit, however these values could be reduced by optimizing process parameters, especially at cooling stage.

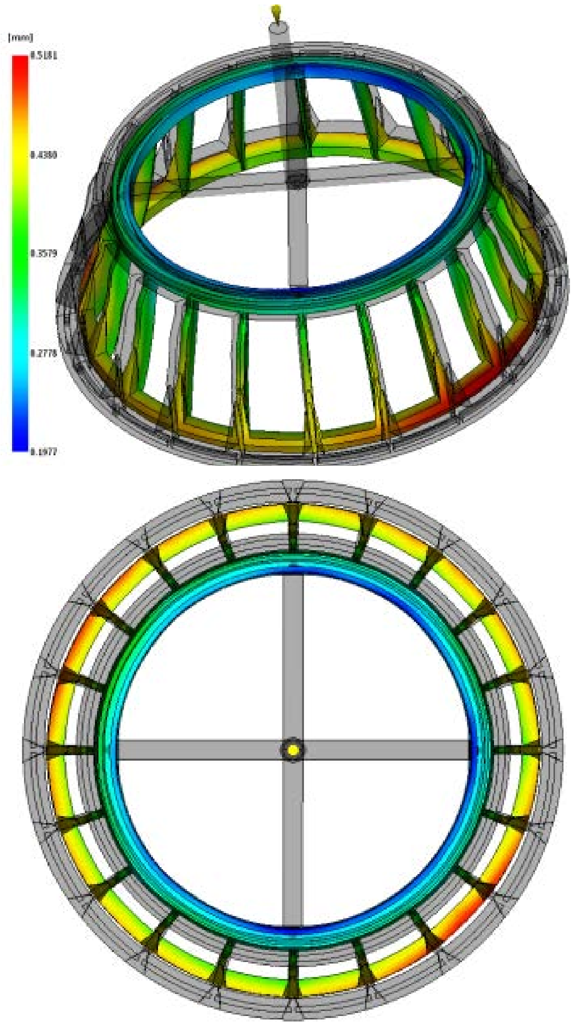


Figure 6: Qualitative post molding deflection for the analyzed study cases

For all different materials the deflection results are shown in Table 3:

Table 3: Results of maximum deflection

CASE	Max. Deflection (mm)
M1-(PA66)	0.5
M2-(PA46)	0.43
M3-(POM)	0.78
M4-(PEEK)	0.97
M5-(PTFE)	0.32
M6-(PEI)	0.35

4. CONCLUSIONS

A FEM analysis has been carried out to determine the most suitable material for a polymeric matrix in a composite focused to a bearing cage component from the point of view of process feasibility and induced mechanics induced by the injection process.

Melt front advancement is adequate for both proposed geometries with an uniform flow and an homogenous end of filling along the part contour. Maximum injection pressure is more adequate for PA46 and PEEK offering values under 60 MPa, and specially PA66 with values under 30 MPa. Regarding to mechanical analysis, better results are achieved by PTFE and PEI, followed by PA66 and PA46 that are also under performance specifications. It can be conclude that polyamide 66, mechanically improved with glass fiber, is the best option for polymeric matrix regarding injection molding process.

On the other hand, a new cage geometry has been tested. The change of geometry, especially cross section thickness, has a direct impact on maximum injection pressure and shear stress induced into the part. Results show that a new geometry with a slightly higher thickness at rolling element cells walls provides lower injection pressures and lower shear stress.

ACKNOWLEDGMENTS

This research has been carried out with the aid of project INNOVA-A1-008/15 granted by Aragon Regional Government in Spain.

REFERENCES

Ciarsolo I., Fernández X., Ruiz de Gopegui U., Zubizarreta C., Abad MD., Mariscal A., Caretti I., Jiménez I., Sánchez-López JC., 2014. Tribological comparison of different C-based coatings in lubricated and unlubricated conditions. Surface & Coatings Technology 257, 278–285.

Ettefaghi, 2013. Preparation and thermal properties of oil-based nanofluid from multi-walled carbon nanotubes and engine oil as nano-lubricant. International. Communications. in Heat and Mass Transfer 46, 142–147.

Fang N., Pugh D., Themudo R. 2007. On stress concentration factors of rolling elements bearing cages. Tribology Transactions 50(4), 445-452.

Forster NH, Rosado L., Brown JR., et al. 2002. The development of carbon-carbon composite cages for rolling element bearings. Tribology Trransactions 45 (1), 127-131.

Gunst U., Zabel W., Valle N. et al, 2010. Investigation of laminated fabric cages used in rolling bearings by ToF-SIMS. Tribology International 43 (5-6), 1005-1011.

Hwang, (2011). Effect of the size and morphology of particles dispersed in nano-oil on friction performance between rotating discs. Journal of Mechanical Science and Technology 25 (11), 2853–2857.

Kohar R., Hrcek S., 2016. Dynamic analysis of Rolling bearings with Elastic Cage. Modern Methods of Construction Design, Lecture notes in Mechanical Engineering 249-254.

Liu, 2011. Lubrication Effect of the Paraffin Oil Filled with Functionalized Multiwalled Carbon Nanotubes for Bismaleimide Resin. Tribology Letters 42, 59–65.

Manier CA, Ziegele H., Barriga J., Goikoetxea J., Woydt M, 2010. Zirconium-based coatings in highly stressed rolling contacts as alternative solution to DLC and ta-C coatings. Wear 269, 770–781.