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FEM BASED SIMULATION OF INJECTED BONE SHAPED PP BASED COMPOSITE MATERIALS

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Abstract: *The paper aims to present a finite element simulation of polypropylene based glass fibers reinforced composite materials using an injection molding manufacturing technology. Two different configurations are used as injected locations and comparisons will be made from the fill and optimization stages of the analysis. A design of experiments (DOE) based on the Taguchi and factorial methods will be used to optimize the injection process and few specific parameters monitored along with the overall composite material behavior, both on time length or function of the melt temperature. The differences encountered based on the aforementioned process and analysis settings can be used for further developments both at the material level (e.g. constitutive selection, volume fraction, effective properties) and manufacturing process.*
Keywords: *finite element, composite, plastic, simulation*

1. INTRODUCTION

Polypropylene (PP) is one of the most widely used thermoplastic polymers in industry due to its excellent cost-to-performance ratio. The selection and use of various material combinations in structural components made from polymers naturally indicate the aforementioned as one of the promising candidate for use along with inorganic fillers as a composite materials with physical, mechanical or thermal improved properties.
Due to its intrinsic nature as semi-crystalline polymer, the plastic deformation occurs both in crystalline and amorphous phases, being a relatively complex phenomenon. Based on this, for a polymer composite subjected to an increasing load the stress transferred to the matrix material induces plastic flow in the matrix and consequently give rise to an irreversible inelastic strain within the composite.
Literature is abundant in references concerning with the inorganic fillers such as glass fibers (GF) that may contribute to the increase of the tensile modulus if embedded in polymer matrices, yet causing the decrease of the strength and toughness of the overall composite. There are several factors that may contribute to these material properties improvement/degradation, such are: poor fiber-matrix adhesion, stress concentration and fillers' aspect ratio, size, shape, surface characteristics and dispersion within the matrix, to underline the most important.
The effective material properties can be retrieved using micromechanical theoretical models, especially the ones that proved less discrepancies with the measured value, such are: Mori-Tanaka, Halpin-Tsai, Cox, etc. These predictors are suitable for arbitrary fiber orientations and different lenght values and lower volume fraction of the fillers. Most theories begin by estimating the properties for a system of fully aligned fibers and then calculating the properties of the effective composite by averaging the unidirectional properties over all directions, weighted by the orientation distribution function.
Injection molding is a common manufacturing process used in plastic industry to produce complex shapes assisted by an outstanding computer-aided technology. Nonetheless, the major problem for product designers is still present but minimized and concerns of the warpage of molded parts prediction. Warpage is caused by variations in shrinkage through the part. For fiber reinforced thermoplastic composites the anisotropic composite property caused by the fiber distribution orientation can become one of the major factors in the part shrinkage.
The process parameters such as injection speed, injection pressure, holding pressure, melting temperature, holding time, cooling time and etc. need to be optimized in order to produce finished plastic parts with good quality. Taguchi method is one of the research preferences in the design of experiments (DOE) analysis.
The present paper aims to present few issues concerning with the influence of the constitutive and injection molding related settings in case of short glass fiber reinforced thermoplastic composite samples. The fiber orientation distribution, individual material properties and different locations of the injection gates are few of the

imposed entrances in the herein study, followed by a Taguchi based design of experiments analysis to determine the influence of few injection molding parameters on the composite bone-shaped parts.

2. NUMERICAL SIMULATION AND PREDICTION

It is very well acknowledged in literature that the injection molding process is generally affected by the following variables: injection speed, materials used, screw rotation speed, backpressure, coolant, cylinder and die temperatures, holding pressure transfer, manifold temperature and spear temperature, etc.

The herein bone shape geometry was investigated using a finite element based method (FEM) by selecting the dual domain mesh type from a commercial software facility (e.g. Moldflow Insight 2010 from Autodesk). The material used was a PP based 30% GF reinforced composite from Sabic Innovative Plastics (USA, trade name – MEV 1006) with the effective mechanical and thermal properties listed in Table 1. For the finite element method based a dual-domain mesh was carried out followed by a mesh diagnosis that proved the overall quality of the discretized part.

A design of experiments (DOE) analysis based on Taguchi and followed by the factorial method was used as an analysis sequence whilst the process insights were compared taking into account 1 and 2 injection locations, respectively. The injection location(s) were set at the end of the holding extremity, which is compulsory to avoid stress locators development. The effective mechanical properties of the composite part were predicted based on the Mori-Tanaka micromechanical model setting as options for the GF orientation during the injection: random distributed at core, aligned at skin.

Table 1: Effective material properties – 30% GF embedded within a PP matrix

Material property	Longitudinal	Transversal
Elastic modulus (GPa)	5.183	2.747
Shear modulus (GPa)	1.224	
Poisson ratio	0.4371	0.4617
CTE x10^{-5} (1/°C)	2.552	6.288
Thermal conductivity (W/m°C)	0.18	

In Figure 1 was represented the volumetric shrinkage at ejection for the double injection locations configuration. As it can be seen the most sensible is the central part of the bone shaped sample but the shrinkage is not accentuated comparatively with the case of a single injection location. The latter setting gives rise to a time range higher than its counterpart with approximately 1 sec.

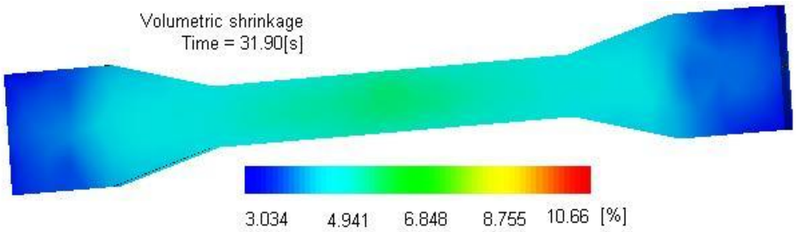
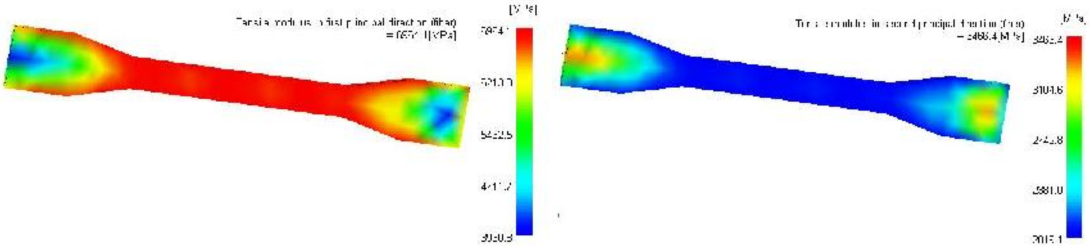


Figure 1: Composite sample's volumetric shrinkage using two injection locations

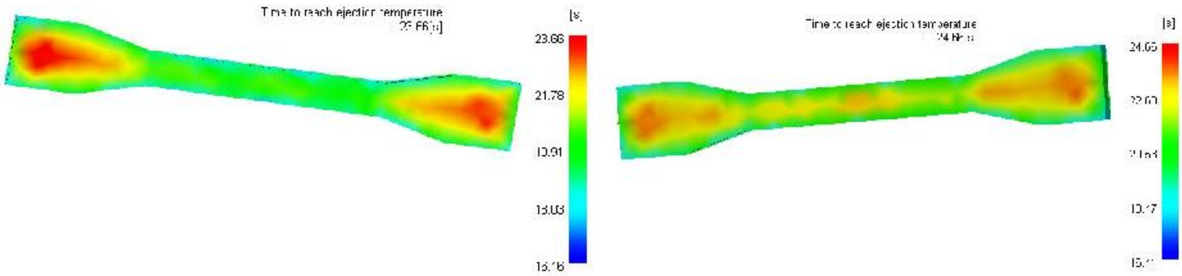
In Figure 2 (a) and (b) are being represented the tensile modulus variation encountered in the longitudinal, respectively transversal directions of the PP based glass fiber reinforced composite sample using a single injection location. Differences in the values can be regarded to the different fiber orientations within the injected parts, both at skin and core levels.



(a) (b)

Figure 2: Tensile modulus in the first (a), respectively second (b) principal directions in case of a single injection gate

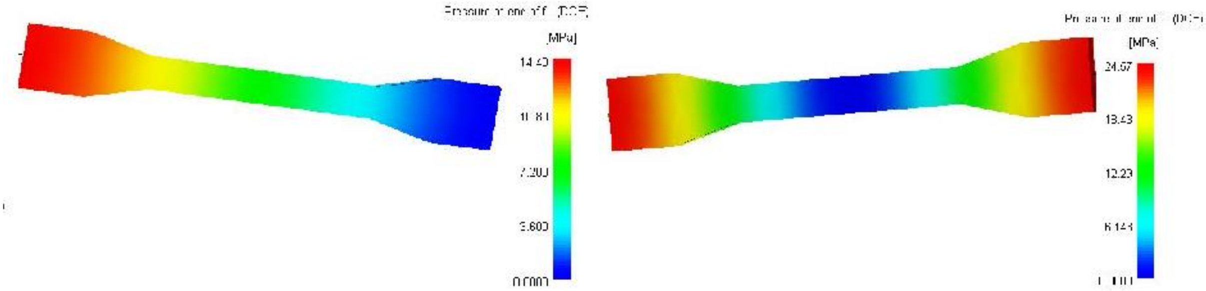
Setting two different injection locations do not necessarily shortens the time until the samples reach the ejection temperature. This can be sized in the figures below, where a higher value was encountered for the double injection location configuration.



(a) (b)

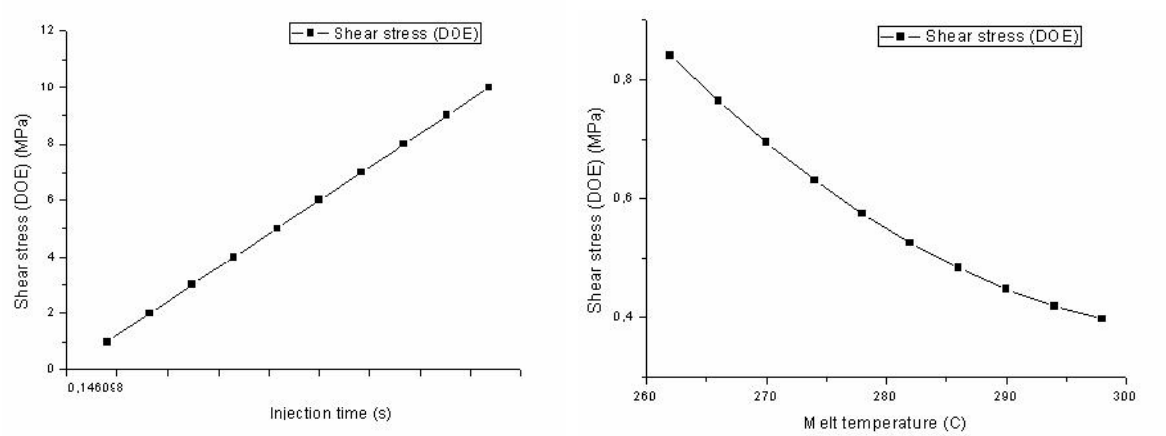
Figure 3: Time to reach ejection temperature for the composite samples using:
a single (a), respectively two injection (b) locations

In Figure 4 (a) and (b) are being plotted the optimized value distributions of the pressure at the end of fill for both configurations under the herein study. As it can be seen, the injection location influences the field distribution as well as the values recorded subsequently.



(a) (b)

Figure 4: Pressure at the end of fill (optimized values) for the composite samples using:
a single (a), respectively two injection (b) locations



(a) (b)

Figure 5: Optimized shear stress values variations:
(a) vs. injection time and 1 injection location (b) vs. melt temperature and 2 injection locations

Apart to the aforementioned indicators, for each analysis stage several quantities or information can be withdrawn with respect to the constitutive/entire composite material or the manufacturing process, such are: the fiber orientation at skin/at core, air traps, average velocity of the injected materials, in-cavity residual stress in both longitudinal and transversal directions, weld lines, shear stress at wall, etc.

Table 2: Process parameter ranges

Parameter	Min	Max
Mold temperature (°C)	40	80
Melt temperature (°C)	250	270
Flow rate (10^3 mm^3/s)	10	80
Packing pressure (MPa)	25	40

For the DOE based on the Taguchi method were weighted and ranked several indicators based on the following factors: melt temperature, global thickness multiplier and injection time, mold wall temperature, packing time and packing profile multiplier. The quality criterion considered herein were: flow front temperature variance, shear stress at wall, injection pressure, clamp force , volumetric shrinkage variance, sink index, total part weight and cycle time.
The parameter ranges, listed in Table 2, were chosen according to the material specification suggested from the plastic manufacturer.

3. CONCLUSIONS

Determining the optimal process parameter setting is a critical work that great influences the productivity, quality and costs of the composite based product manufacturing and production. Taguchi process parameter design method is one of the methods preferred in engineering to determine the optimal parameter settings and as is known is based upon three stages, as follows: concept design or system design, parameter design, tolerance design. Taguchi approach has potential for savings in experimental time and cost on product or process development and quality improvement. There is general agreement that off-line experiments during product or process design stage are of great value. Reducing quality loss by designing the products and processes to be insensitive to variation in noise variables is a novel concept to statisticians and quality engineers.
The results herein are revealing the fact that the melting temperature is the most significant parameter while the injection speed is the insignificant parameter. The presence of a second injection location does influence the injection manufacturing process, contributing to volumetric shrinkage of the composite sample in the most sensitive part of it. The significant factors can be determined performing an ANOVA analysis. The fiber distribution within the composite sample or at the skin surfaces represent another major influencing factor that should be address individually and in connection to the manufacturing parameters.
Further studies can be address with respect to the herein subject by integrating a supplementary methodology to the finite element based simulation, namely artificial intelligence. Neural network, genetic algorithms or fuzzy logic represents few of the approaches that can aid these optimization processes.

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