Multidisciplinary Studies Regarding the Residual Stress Minimization in Polymeric Injected Parts

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The paper presents the multidisciplinary studies dedicated to the minimization of the residual stresses in an Acrylonitrile-Butadiene-Styrene part. The first stage of the study consists of an experimental research employed to measure the physical characteristics of the polymeric material. The next stage is a simulation of the moulding process for a plate-wise specimen made of the material previously tested, being interested by the values of the residual stresses. The next stage is the experimental research of the residual stresses by the use of the hole-drilling method applied on the previously simulated plate-wise specimen. The results of the two studies are close one to the other and the conclusion regarding the material and the parameters employed for the simulation are used for the next study dedicated to the simulation of the moulding process for a complex part. Several studies were performed in order to find the best parameters of the moulding process which lead to a minimum level of the residual stresses. Other parts made of the same material may be also simulated in order to minimize the residual stresses. We conclude considering that a high degree of confidence regarding the results of the numerical model may be achieved only if the results of experimental studies are employed.

Keywords: polymeric part, residual stress, experiment, numerical model, applications

Most of the actual parts are made of moulded polymeric materials which have great advantages in comparison with the classic materials. Large chemical companies produce most of the 200 million tones per year of plastic materials. Even the manufacturing of the moulds is expensive, their use have several advantages, regarding the resulting parts: shapes with great complexity, automatic control of the moulding process, high speed of the technological process, accuracy and quality of the final product, low or null costs for the post-processing of the parts.

The quality of the final part is a complex concept which may be approached from different points of view. Research offers the instruments employed to define the best strategies for the effective production of moulded polymers: materials and parameters of the moulding process.

Nowadays science offers both numerical and experimental methods to investigate the phenomena related to the moulding process, [1, 2, 3]. Interdisciplinary approaches which use the results of the both types of studies previously mentioned are the most accurate methods of investigation, [4].

Problem formulation

Accurate models of mechanical parts lead to the minimization of the manufacturing costs, by offering predictions regarding the behaviour of the mechanical part in exploitation conditions.

An accurate model of a mechanical part requires a set of precise scientifical information which must have a high degree of confidence: characteristics of the material, parameters of the molding process, predictions regarding the stresses, air traps, weld lines, temperature gradients. The general organization of the research studies is presented in figure 1.

Using this research strategy, [5], theoretical approaches (numerical methods) rely on real information (experimental data) in order to solve a practical problem (in this case, the most effective parameters of the molding process). Mathematical aspects of the molding process are important and interesting, [6], [7] and they are a necessary stage for a thorough research.

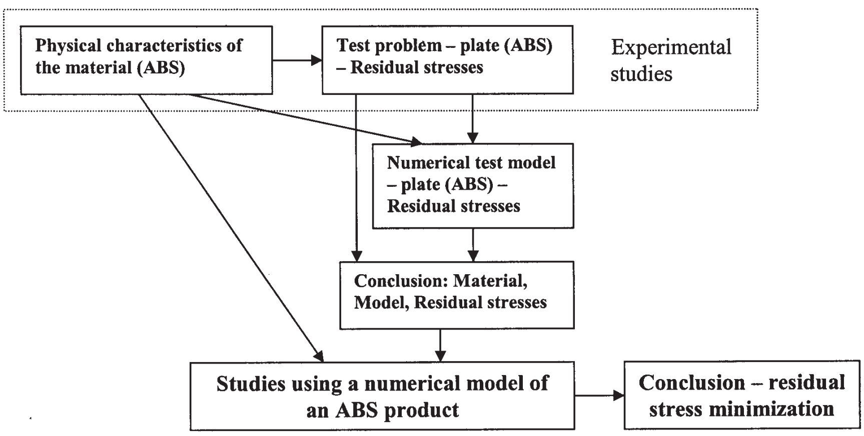

Fig. 1. General organization of the research studies

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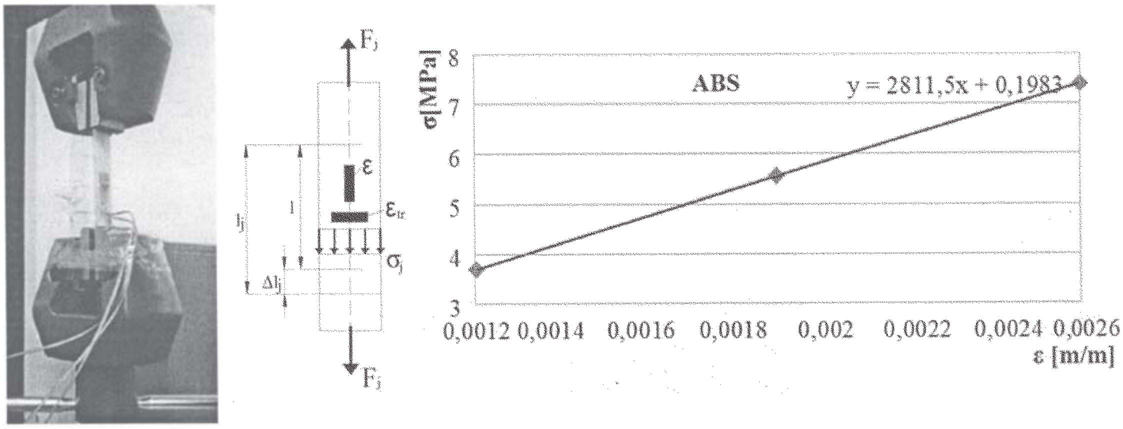

Fig. 2. Experimental research of the ABS material constants

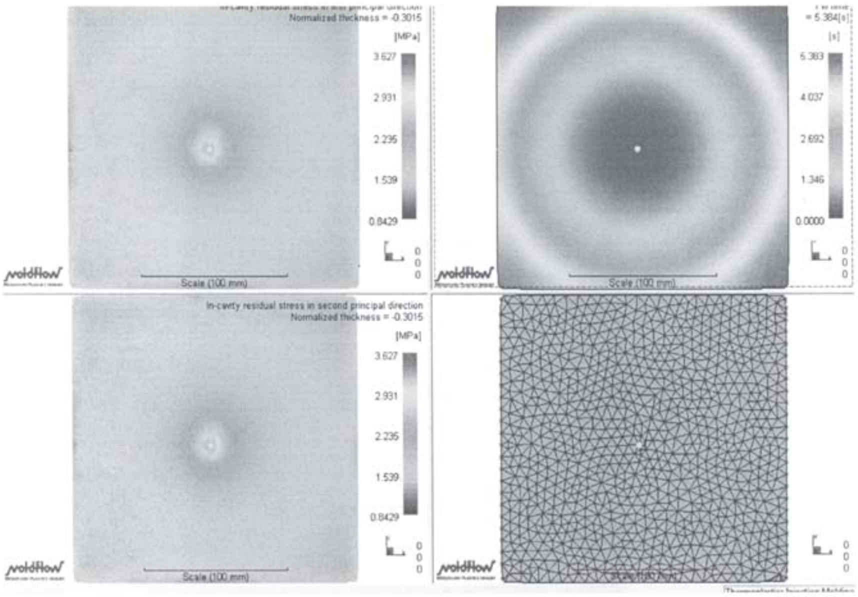

Fig. 3. Simulation of the residual stress distribution for different units of the mesh. Using Moldflow Plastics Insight, [9], [10], several studies were performed, for different sizes of the mesh: 8, 7, 6, 5, 4, 3, 2 mm

Experimental research of the ABS material constants

Young's modulus and Poisson's ratio of the given ABS material are computed using experimental data, [8], resulted from the strain gauges installed on a beam in tension, figure 2.

Finally, the values of the elastic constants of the ABS material are E=2811.5 MPa,ν=0.4038 and G=1001.4 MPa.

Finite element model of the specimen

The test problem considers a 5 mm thickness plate presented in figure 3. The parameters of the injection process are: mould surface temperature 50°C, melt temperature, 230°C, fill time 5.653s, cooling time 20s, maximum injection pressure inside the mold 11,7MPa. The quality of the melt, which is hard to control, has a direct influence onto the quality of the final part.

Experimental study of residual stresses of the specimen

The results of the simulation are verified using an experimental investigation based on a standardized method described in ASTM Standard E837, the hole-drilling method, [11-14].

The experiment employed three element strain gauge rosettes installed in two measurement points which are connected to a Vishay Micro-Measurements Model P3 multichannel static strain indicator and a precision milling guide, Model RS-200. The coefficients of the rosettes and the data reduction methodology may be found in the literature, [15].

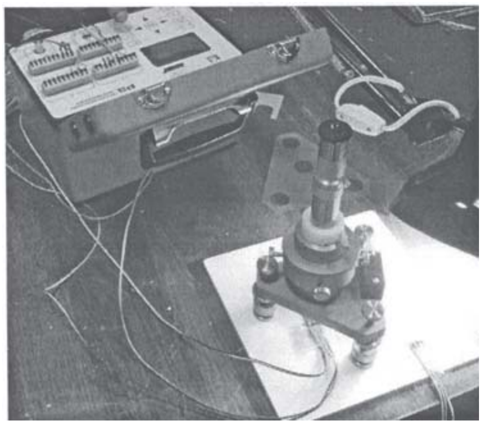

Fig. 4. Aspects from the experiment - the hole-drilling method

Comparative study of the results

Both investigations, numerical and experimental, are dedicated to the same purpose, to asses the residual stresses state in the ABS plate-wise test-part.

Analyzing the values presented in figure 5, one can notice:

- the curves of the values of the stresses in the measurement points "a" and "b" have the same monotony;
- there are no peaks or apparently 'random' values, the numerical model being considered stable; moreover, repeating the numerical study for the same size of the mesh, it results the same overall values of the stresses, the slight differences being explained by the automatic

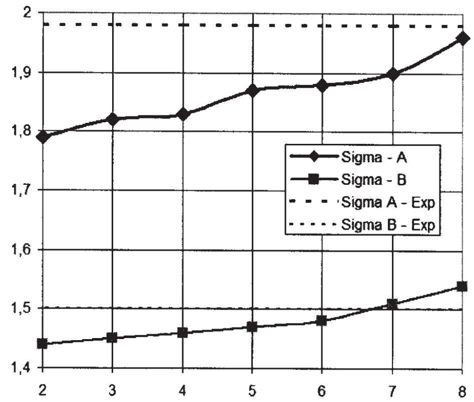

Fig. 5. Evolution of the stresses in the plate with respect with the size of the mesh

generated mesh which is different for each execution of the program; even though, taking into account all these aspects it can be noticed that the numerical model is stable;

- the size of the mesh recommended by the program is 5 mm, the errors of the values of the stresses resulted from the numerical model, with respect to the values resulted from the experiment are $\varepsilon^{'a'}_{5mm}$ = 5.56% and $\varepsilon^{'b'}_{5mm}$ = 2.00%; the maximum values of the errors are $\varepsilon^{'a'}_{2mm}$ = 9.59% and $\varepsilon^{'b'}_{2mm}$ = 4.00%; taking into account these values it may be concluded that the numerical model is accurate. It results that the numerical model is accurate and the model of the material may be used for subsequent studies regarding a part manufactured from the same ABS material.

Application of the results for the finite element model of a mechanical part

The knowledge acquired from the previous studies is used for the simulation of the moulding of a real part, figure 6, a. The discretization of the part and of the runner system is presented in figure 6, b. The designation of the regions is presented in figure 6, c.

The residual stresses are computed using Moldflow Plastics Insight, for the different sizes of the mesh (Δx = 1mm, Δx = 2 mm, Δx = 3 mm and for different melt temperatures (200, 210, 220, 230, 240, 250, 260°C).

In order to analyze the data, two types of diagrams are drawn for each region. The first one presents the variation of the residual stress with respect to the size of the mesh, figure 7. The second diagram presents the variation of the residual stress with respect to the melt temperature and it is presented in figure 8.

Results and discussions

According to the figures 6, 7 and 8, one can notice the following connections:

a) ABS molded parts b) Discretization of the part c) Symbols of the regions

Fig. 6. ABS molded parts

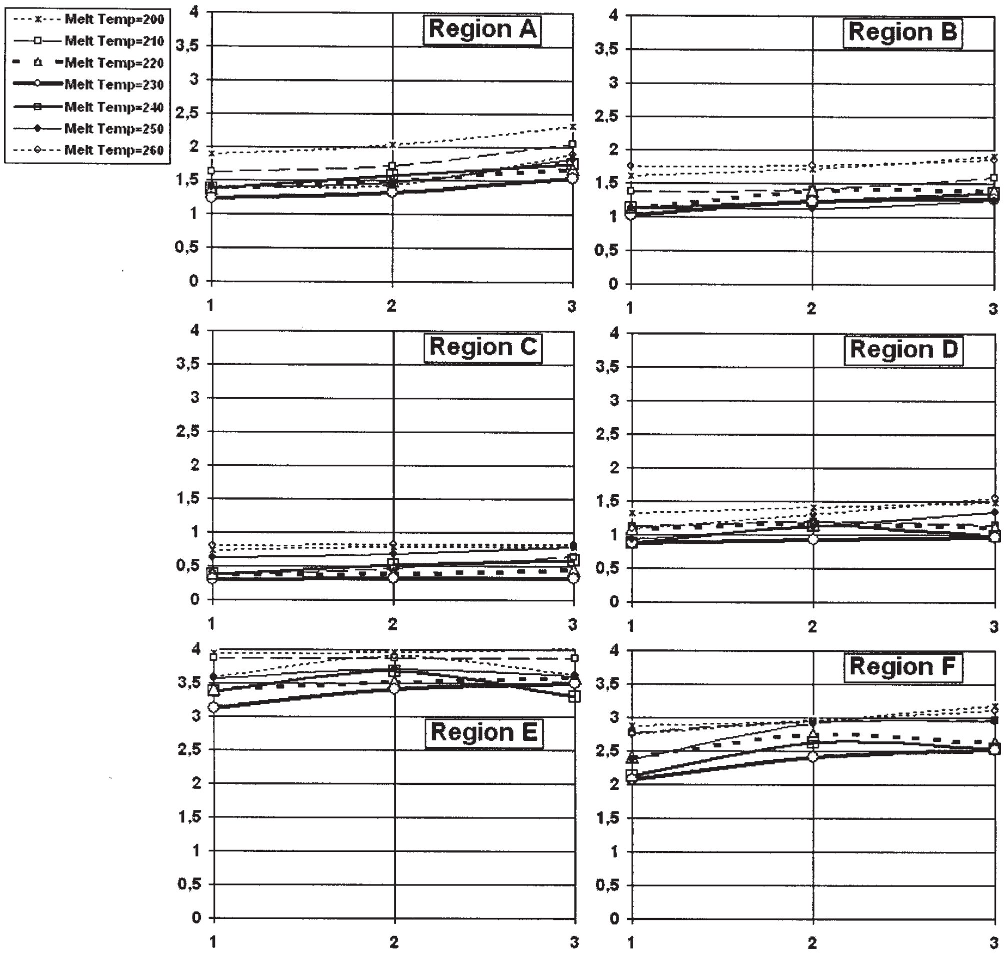

Fig. 7. Overall stresses variation (for each region of the part) with respect to the mesh size

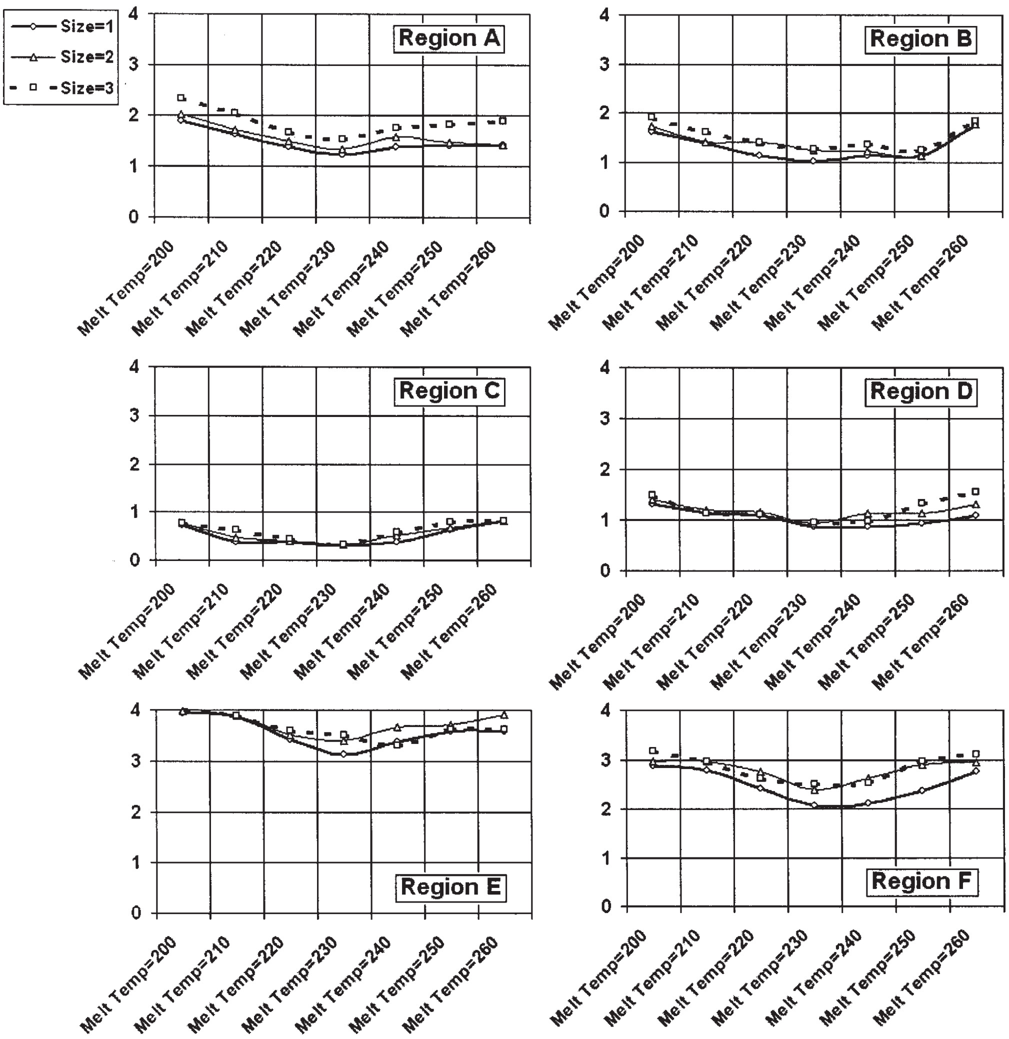

Fig. 8 . Variation of the overall stresses for each region of the part, with respect to the melt temperature

- the part has no symmetry, so simplifying aspects regarding the symmetry in the analyses of the according phenomena (filling, cooling, residual stress apparition) cannot be considered;
- the maximum values of the stresses are maximum analytical values and they are displayed by the program as the upmost boundary of the range; these values are computed on theoretical bases and they appear in the running system of the mould; the values are not large enough to be significant for the study of this part; having a low degree of relevancy for the regions of the part, the analysis is focused on the maximum residual stresses of the regions previously identified by letters (fig. 6), where significant lower values can be found;
- region D is the first region filled with melt; the overall range of stresses of this region is 0.875 up to 1.547 MPa; the stresses have no significant variations with respect to the temperature of the melt; as a general aspect, the largest stresses are in the area located next to region E, but the concrete values cannot be considered large;
- region E connects region F to D; the largest values of the residual stresses are recorded in this region, the range being 3.125 MPa up to 4.023 MPa;
- region F has the smallest volume; the range of stresses in this region is 2.071 MPa up to 3.176 MPa;
- region C connects region D to regions B and A; the range of stresses is 0.308 MPa up to 0.825 MPa; these values are the smallest in comparison with the other regions; for all the input data there may be noticed that the stresses have no large variations in this region;
- region B connects region C to region A; the range of the stresses is 1.016 MPa up to 1.906 MPa; the stresses have no large variations in this region;
- region A is the last region filled with melt; there are gradients of the residual stresses; the range of the stresses is 1.225 MPa up to 2.329 MPa; the maximum values of the stresses are recorded to the upmost end of the region and at the lowest end, which is at the boundary of region B.

Based on the previous analysis, the following overall concluding remarks were drawn:

- for the whole part the residual stresses are low, so a better redesign is not necessary from this point of view;
- each region has a specific range of values of the stresses, so an analysis for each region was necessary;
- for each region the range of values of the residual stresses is narrow with respect to the mesh size, which denotes a convergence of the results; that means that the model is stable and accurate;
- the largest values of the stresses are recorded for the extreme values of the melt, 200 and 260°C, especially for 200°C, so the technological conditions may be properly adjusted;
- the largest values of the stresses are recorded for the largest size of the mesh, so even the computer time to solve a version with a small size of the mesh is significant larger, it is important to have an overall vision regarding the state of stresses for several sizes of the mesh.

A decision based on the values of the residual stresses may be taken with respect to one or several criteria, such as:

- minimization of the residual stresses in the most stressed areas;

- minimization of the residual stresses in the regions with large loads in running conditions.

Some other measures may be also taken, like:

- a new location of the runner system;

-decision regarding the necessity of annealing or quenching operations for the part.

Conclusion

The research method presented in the paper uses the best features of the experimental and numerical studies in order to solve a practical problem concerning a polymer part.

Regarding the experiment, both the viscoelastic behaviour of the material and the experimental conditions, have a great influence on the results of the measurements. Special care was dedicated to avoid the apparition of the parasitic effects.

For the plate-wise specimen the results of the experimental and of the numerical studies are close one to the other. The research procedure was compared with the methodology presented in [16], which is far more complex.

Various studies may be done once the material characteristics and numerical model particulars are known.

The ABS part was studied using different mesh sizes and several technological conditions and significant conclusions were drawn.

Even the study of a real part may look theoretical, the results have a high degree of confidence only if experimental values are employed to define and to calibrate the numerical model.

The study offers information and a methodology which may be applied in practical conditions for a large number of parts manufactured from the same material and for several technological constraints, the conclusions being an effective support in the decision making process.

*Acknowledgements***:** *Ideas presented in the paper are the result of the research activities of the ID1223 project, under the supervision of the National University Research Council (CNCSIS), Romania, [17]. We mention the support of the Constanta Maritime University who offered the financial aid for the experimental research presented in the paper. The experimental studies mentioned in the paper were conducted by professor Paul Bârsănescu, from the Technical University of Iasi to whom we express our gratitude. We remind the support of professor Cătălin Fetăcău, who allowed our access to the numerical analysis software of the Polymeric Materials Research Laboratory belonging to the "Dunărea de Jos" University of Galaţi.We also mention the aid offered by Matris Metal Plast, Bucharest, where the mould and the mould model were designed and manufactured.*

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Manuscript received: 16.09.2009