REDUCTION OF DETRIMENTAL MECHANICAL ANISOTROPY OF LCP COMPOSITES

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ABSTRACT

This investigation was focused on elucidation of materials and process factors that determine mechanical isotropy or anisotropy of liquid crystalline polymer or LCP composite based injection moulded articles. The principal parameter used to monitor mechanical anisotropy was tensile strength. An objective was also to find methods that can be used to decrease detrimental anisotropy of LCP composites. The ultimate goal is to develop an LCP material and moulding process to make possible production of mobile phone and portable computer casings from an isotropic LCP composite.

The experiments were carried out in order to elucidate effects of filling factor of LCP with a new hybride filler on mechanical isotropy or anisotropy of castings. Another objective was to study process factors of injection moulding method that have effects on LCP products isotropy / anisotropy. Specific process parameters studied were injection speed in speed controlled machines and injection pressure in a pressure controlled machine and thickness of the cavity in mould. A new tool for the measurement of mechanical anisotropy and strengths of knit and weld lines of moulded thin wall castings was also developed and used for obtaining most of the data presented in this paper.

The results indicate that the detrimental anisotropy of LCP products can be significantly decreased by restructuring composite microstructure and by the optimisation of the chemical composition of LCP composite as well as optimisation of injection moulding parameters.

1. INTRODUCTION

Highly oriented polymers or polymer composites have different mechanical properties in injection moulded products depending on the geometrical direction of a test specimen under a mechanical stress. The tensile strength, the impact strength, the stiffness and other mechanical properties are usually higher in the direction of orientation or in the machine direction compared to the transverse direction. Only a few investigations have been published about the origin and the interpretations of the effects of parameters that control the formation of the mechanical anisotropy of LCP materials. One paper deals this matter using molecular modelling approach [1]. Several investigations have been published, however, about synthesis, liquid crystallinity, microstructure and properties of aromatic polyesters based on hydroxybenzoic acid and other aromatic monomers used as the model basic polymers in this project [2, 3]. The mechanical anisotropy of injection moulded plaques of a liquid crystalline polymer based on a copolymer of p-hydroxybenzoic acid, isophthalic acid, and hydroquinone has also been studied [4]. The inhomogeniety of the elastic anisotropy has been determined by a combination of static and ultrasonic measurements. Results are discussed to describe the relationship between mechanical anisotropy and molecular orientation.

Mechanical anisotropy of materials may be useful or detrimental depending on end use applications. Extremely high uniaxial strength of liquid crystalline polymers or composites based on these polymers is advantageous in rod-like products, ropes and cables. Anisotropy may, however, be harmful or detrimental in mobile phone and lap top computer casings where equal mechanical strength is necessary for at least in x- and y- directions of the sheet-like packaging products. The products may not therefore pass tests where extensive variation of environmental parameters and mechanical stresses are investigated.

The reason for this extensive orientation is the formation of rigid fibrous structure of polymer chains in moulding of thin specimens. The decrease of the tensile strength of HNA-HBA LCP in transverse to flow direction is related to decrease of LCP tensile strength in non-oriented core layer of injection moulded test bars compared to the highly oriented skin layer of the same bars. It was shown by SEM and tensile strength measurements [5] that the core layer has only 50 % strength and contains LCP structures of spherical domain compared to skin layer strength with fibrillous LCP structures.

The tensile strength in the transverse direction of LCP orientation may be only about one half to one third from the strength in the direction of orientation. A particular consequence in the applications is fracture formation and deterioration of moulded parts under extensive mechanical and environmental stresses.

If liquid crystallinity and LCP molecular orientation in micro scale can be prevailed without drawbacks caused by material anisotropy several new high volume applications can be found for LCP composites, particularly replacing metallic and ceramic parts or articles.

The research hypothesis in our experimental work was to find out and evaluate parameters that have clear effect on isotropy / anisotropy of injection moulded thin walled LCP articles. Tensile strength was selected as the primary parameter to measure effects of different variables on mechanical anisotropy. It can be measured with a great reproducibility and results can be interpreted unambiguously.

Stiffness is another parameter that can be obtained from tensile strength tests and is another mechanical property, which has a great significance in evaluating the properties of thin walled LCP composite products for the target applications. Results and discussions about anisotropy of stiffness of LCP composites will be published later. The effects of the parameters on tensile strength will be discussed in this paper. If a macro isotropic micro liquid crystalline composite could be developed tensile strength should be identical in all x, y, z directions. This investigation was, however, simplified in a way that only x and y directions were studied. In sheet-like electronics packaging applications x-y isotropy is the most important. Material properties of injection moulded castings in melt flow direction (machine direction or fibre direction) and transverse to melt flow direction or machine direction were determined and discussed. At the same time strengths of knit lines and weld lines were also obtained.

Effects of wall thickness of injection moulded castings, effects of injection moulding process parameters and effects of the most important material composition parameters will be described and discussed.

2. EXPERIMENTAL

Commercial liquid crystalline copolymers based on hydroxybenzoic acid and hydroxynaphthoic acid and its high-temperature modification were obtained / purchased from Ticona GmbH, Germany. Talc used as inorganic starting material was obtained from Mondominerals Ltd, Finland. A Demag Ergotec injection moulding machine was used for production of test specimens by the speed controlled process and an Engel X-melt machine for production of specimens with the pressure controlled method. LCPHITEC test mould developed in VTT is described in Fig. 1. Several test specimens we moulded from each composite material produced.

An LCPHITEC test mould for determination of anisotropic tensile properties of LCP composites was planned and fabricated at VTT in this project. Figures 1 a – c depict castings and test bars produced by this tool. Fig. 1a shows the general geometrical structure of castings with dimensions in millimetres. Injection point of the LCP melt is in the dark shadowed centre of the figure. From that injection point the LCP melt flows with a very high speed up to 1000 mm per sec into the two separate sections of the mould. The first section at the upper part of the mould cavity produces solid LCP plate from which the oriented melt flow test bar (3) and the transverse to flow direction bar (4) are cut as shown in Figure 1b. The lower part of the mould cavity in Fig. 1b produces the knit line (hot joint) (2) bar behind a round hole and the weld line (cold joint) (1) bar behind a rectangular hole. The dimensions of the mini test bars are shown in Fig. 1c. Several test specimens were moulded from each composite material produced. From these materials corresponding dog bone test bars were produced by the water cutting technique. For preliminary checking of tensile strength properties three test bars were measured. If significant effects of a parameter studied on tensile strength was observed in the results obtained at least five dog bone bars were measured and the average value was used for further work.

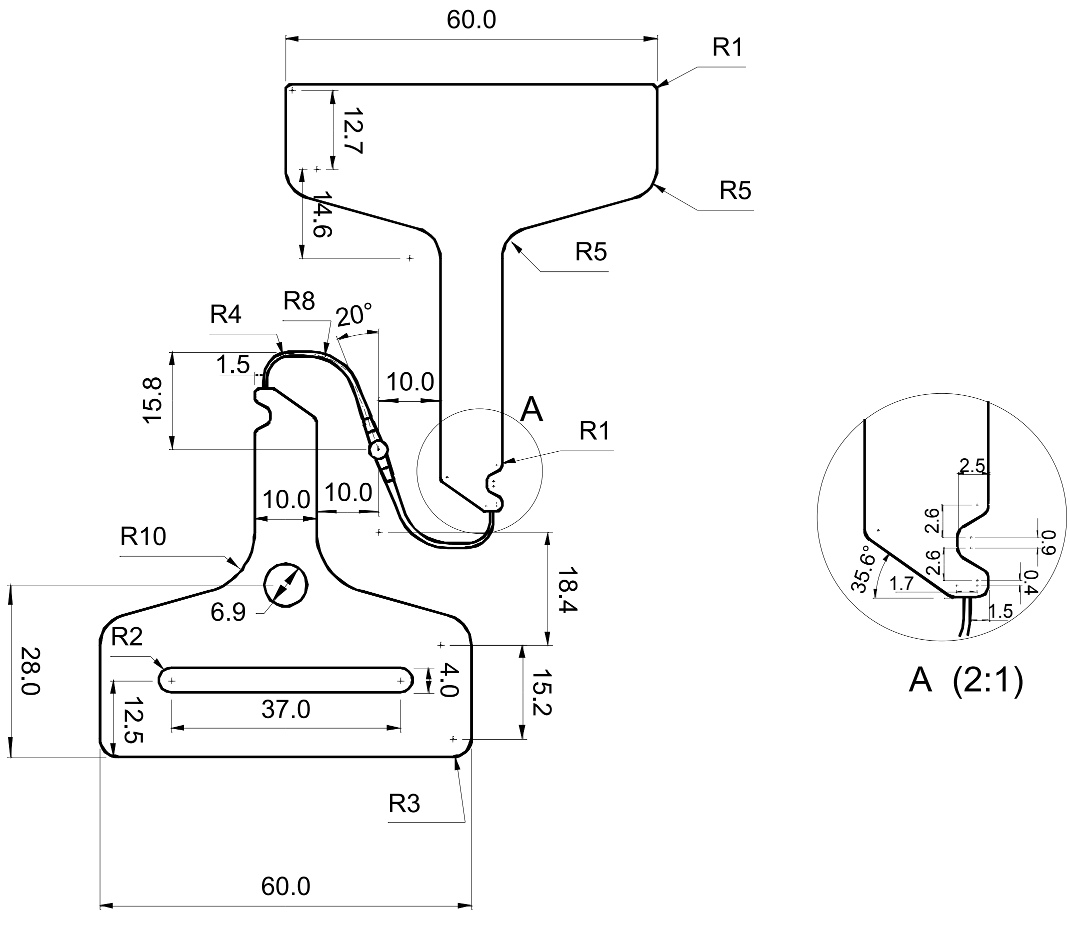

Fig. 1 a Dimensions of the casting using LCPHITEC mould developed in the project.

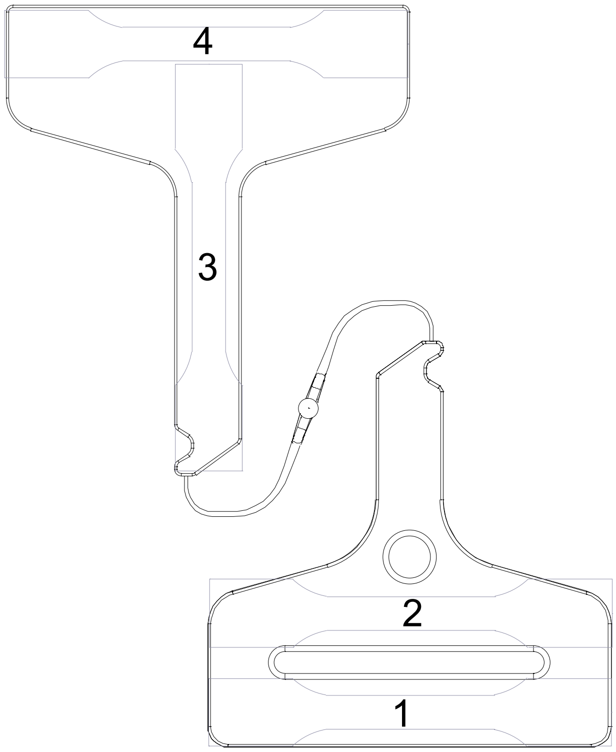

Fig. 1 b Cutting of the test bars from the casting.

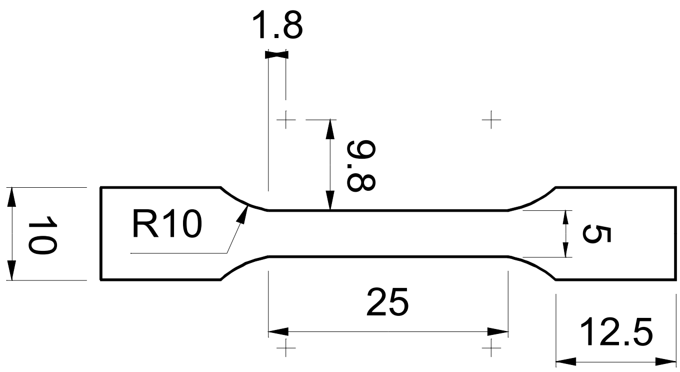

Fig. 1 c Dimensions of the test bar.

3. RESULTS AND DISCUSSION

The most important parameters that may affect on formation of detrimental mechanical anisotropy in our target applications were first considered on the basis of earlier experimental knowledge and theoretical physical and chemical considerations. Effects of thickness of moulded sheet-like parts simulating electronics packaging applications and any applications that require isotropic strength properties are thereafter discussed. Finally effects of injection moulding parameters and LCP material composition will be considered.

Results are considered in order to find factors that determine the mechanical anisotropy of LCP materials and factors that can be modified to produce an LCP material that possesses the necessary isotropic properties for end user applications. The goal article must have similar material properties in each direction but still contain the advantageous LCP material properties like low viscosity in melt stage, very good dimensional stability, chemical and high temperature stability and fire retardant property without harmful additives.

3.1 Effect of Wall Thickness of Moulded Parts on Mechanical Strength Anisotropy

Optimising thickness of sheet-like moulded parts that can be used for packaging of communication electronics products like mobile phones or transportable computers was investigated first. Wall thickness of 2.0, 0.8 and 0.5 mm were studied. Wall thickness of 0.5 mm gave the strongest and the most isotropic and promising properties.

Results indicate that the transverse direction strength is only 37 % of the machine strength or in other words melt orientation strength for the basic polymer used in this study and 2.0 mm thick castings while the corresponding strength for the same basic polymer and 0.5 mm thick castings is improved to 43 %. Similarly the strength of weld line (cold joint) compared to the strength of knit line (hot joint) was improved from 32 % to 76 % by changing 2.0 mm wall-thickness mould to about 0,5 mm wall-thickness specimens producing mould.

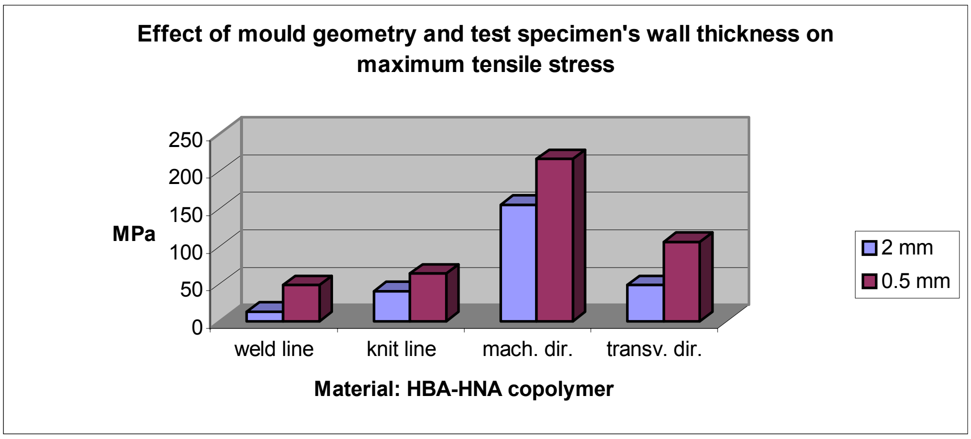

Fig. 2 Effect of wall thickness.

It can be concluded that by making the walls of castings thinner both the tensile strength and the strength isotropy can be significantly improved. A further advantage is that the cold joints (weld lines) become now nearly as strong as the hot joints (knit lines). A practical advantage in end user applications like mobile phone casings is also savings in materials costs when thinner but still strong casings and other parts can be produced and used for final applications.

3.1 Effects of Injection Moulding Parameters

The most important finding in various effects of process parameters was that pressure controlled injection-moulding method gave the most isotropic castings when highest obtainable injection pressure 2600 bar was applied. This is shown in Fig. 3.

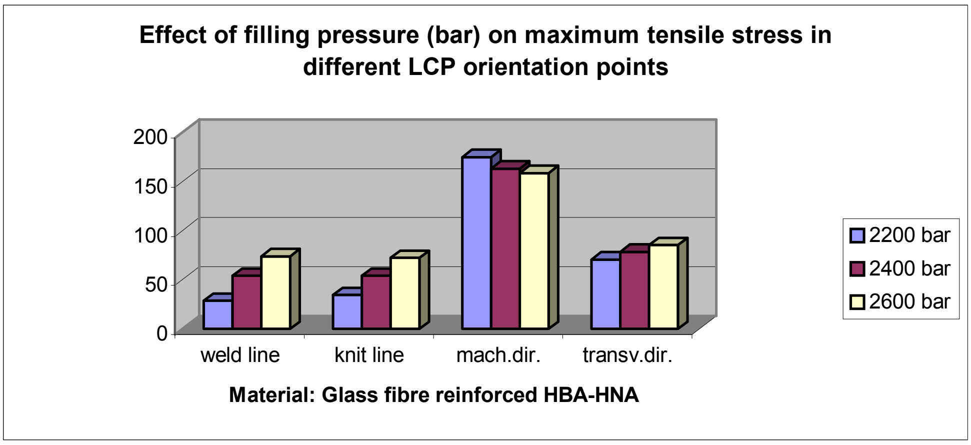

Fig. 3 Effect of Injection Pressure on Isotropy of LCP Composite Products.

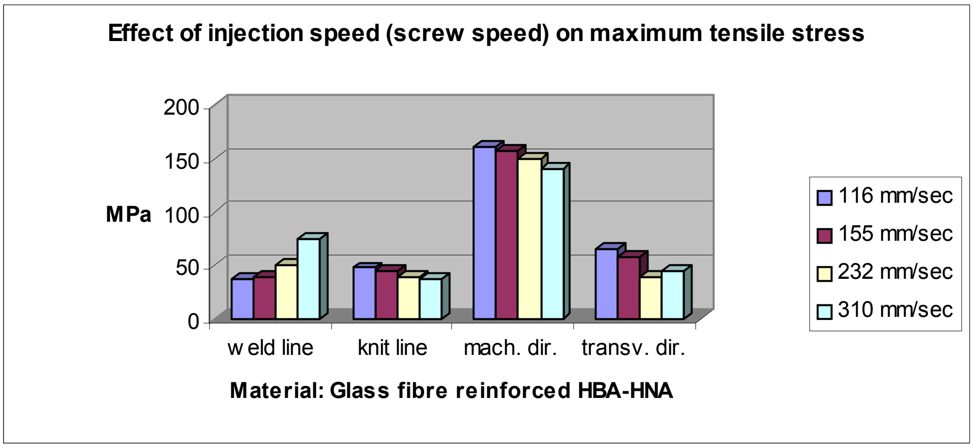

Fig. 4 Effect of Injection Speed on isotropy of LCP Composite Products

With speed-controlled injections the highest speed studied was the most advantageous as shown in Fig. 4. This set of speed-controlled experiments does not contain high-speed injections up to 1000 cm per sec, which in later experiments proved to be even more advantageous. However, pressure controlled injection method gave slightly better results when anisotropy, strength of knit and weld lines and the average strength of moulded specimens is compared with specimens moulded by speed controlled injection process. A possible explanation is that pressure controlled moulding may be more gentle or adaptive. In the beginning of the injection cycle pressure controlled LCP melt shot has a very high speed but after gradual filling of the mould injection speed decreases. For this reason final equilibration and ordering of polymers and fillers in mould occurs more slowly and carefully leading to a more balanced microstructure of LCP composite.

3.3 Effects of Material Composition on Improvement of Mechanical Isotropy

Figures 5 and 6 show the effects of filling factor using 200 and 1000 mm per sec injection speed on tensile strengths of castings made of the LCP organic-inorganic nanocomposite developed in this project [6].

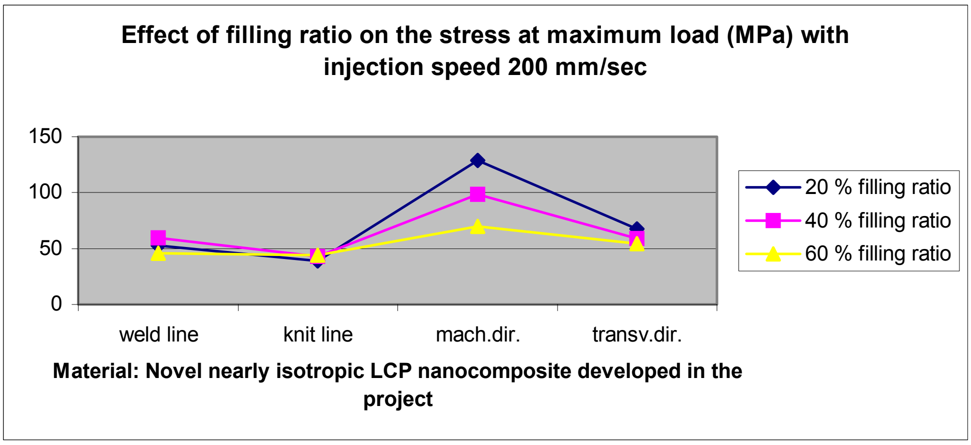

Fig. 5 Effect of filling factor of a basic LCP with a preprocessed mineral filler using 200 mm per sec injection speed

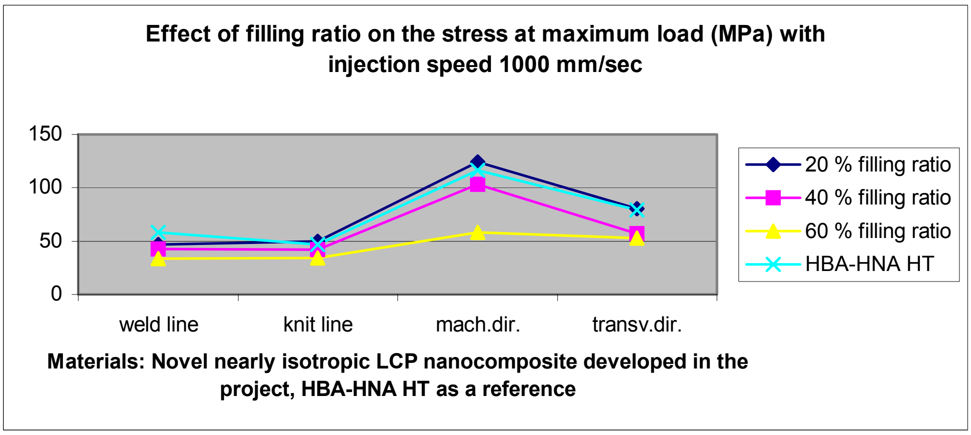

Fig. 6 Effect of filling factor of a basic LCP with preprocessed mineral filler using 1000 mm per sec injection speed.

This set of experiments indicates that the higher the filling rate of the new inorganic-organic filler the more isotropic is the LCP nanocomposite. It became also clear that very high filling speed improves the isotropy.

4. CONCLUSIONS

Our research indicated that there are certain parameters connected to dimensions of castings, injection moulding process and composite material composition that greatly influence on isotropy / anisotropy properties of LCP based composites. By adjusting these key parameters it is possible to produce nearly isotropic LCP material or an injection moulded part based on this material.

Such products are needed for some very demanding electronics and energy production end user applications. It was shown that 0.5 mm wall thickness, pressure controlled injection method and an organic-inorganic LCP filler material could be used to produce a nearly isotopic LCP parts which also have nearly similar knit line and weld line strength as the basic material. Further improvement of the properties of this material is being carried out.

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