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DESIGN AND IMPLEMENTATION OF A GLASS FIBER REINFORCED HYBRID POLYMER MATRIX COMPOSITE WASHING MACHINE DRUM SUPPORT REPLACING CAST ALUMINUM ALLOY

Today, polymeric composites are mostly used in statically loaded rather than dynamic load-bearing parts in machines. Their light weightiness, durability, relatively low prices, flexibility in their use, and fast production features constantly have been opening new ways for their use. In this study, the design, analysis, and experimental verification of a short glass fiber reinforced polyamide + polyphthalamide hybrid polymer machine part functioning under dynamically varying loads and harsh chemical and heated environments is presented. One such machine part is a washing machine drum support to which no composite material had ever been applied successfully before, as known to the authors. The study shows that at least 50% short glass fiber reinforcement, long term polymeric material mechanical properties as well as certain geometric stiffening modifications have been applied for this composite part to function as an equivalent cast aluminum alloy part.

Keywords: hybrid polymer composite, drum support, metal replacement, washing machine

INTRODUCTION

Nowadays, reinforced polymers are used for their high specific strength and stiffness as well as high fracture toughness, good abrasion, impact, corrosion and fatigue resistances, low-cost solutions at all levels of engineering areas [1, 2]. A washing machine is one of the most used home appliances. Washing machines are also known as laundry machines, washers, and clothes washers. They wash clothes and home textiles with water and detergents at relatively high temperatures. The earliest machines were used as hand-operated when electricity was not common. A washing machine includes plastic, metal, and electronic parts. Metal parts increase the weight of a washing machine [3, 4].

In front loading modern washing machines, there is a star-shaped part (also known as a Drum Support or Spider Arm) fixed to the drum that transmits the motion from the electric motor to the drum via a belt. This support was previously made of steel but nowadays it is manufactured using cast aluminum alloys. A drum support should have at least 10 years of economic lifetime. It is exposed to different factors such as varying rotating loads, torques, and speeds as well as detergents and hot water in the drum casing [5].

Global competitiveness necessitates the cost reductions of both the part material and its production method [6]. Apart from the perforated steel drum, reduction of the support weight as well as that of the main shaft can provide less energy consumption. A washing machine drum rotates at up to 1600 rpm. Extreme bending moment, torque, and shear loadings limit the flexibility to deal with the design parameters of the main shaft. So, the next reasonable candidate for material conversion and topological optimization becomes the drum support of a washing machine drive mechanism [7, 8].

MATERIAL AND METHOD

Further cost and weight reductions leading to low energy consumption in a washing machine requires a conversion of the Support material from metal alloy to a composite. Material changing of an industrial part requires evaluation of strength, cost, and environmental considerations [9, 10]. The interconnections among these and a redesign procedure to follow for a successful material conversion is given in reference [11].

An Al-Si alloy support is prone to damage due to galvanic corrosion and is produced by the costly die casting. The die casting process requires continuous heat supply up to 650°C. On the other hand, processing temperatures of polymer-based composites in injection molding may reach up to 360°C at most. As a candidate for Al-Si alloy replacement, the Polyamide and its derivatives are widely used as thermoplastic matrix materials in composites and additions of short glass fiber reinforcement improves their mechanical properties [12]. In the experimental part of this study, a custom designed short glass fiber reinforced polyamide + polyphthalamide hybrid polymer composite material (sGf+[*PA*+*PPA*]) has been considered for replacement of the *Al-Si* alloy of the drum support. The respective mechanical properties of these materials are given in Table 1.

TABLE 1. **Mechanical properties of cast Al-Si alloy and heat/moisture conditioned sGf+[*PA*+*PPA*] composite**

Material	Tensile strength [MPa]	0.2% Strength/ heat defl. temp.	Modulus of elasticity [GPa]	Poisson's Ratio	Elongation at break	Density [kg/m^3]
Al-Si alloy	270	160 MPa	73	0.33	2%	2600
sGf+[*PA*+*PPA*]	207	263°C	19	0.39	3%	1720

The reduction in material stiffness due to conversion from an Al-Si alloy to a hybrid polymer composite has been remedied by geometric improvements in the varying cross-sectional area of the support and long term mechanical properties, as well as by using additional reinforcing ribs wherever found to be necessary. Solidworks® Simulation Premium software-based static and dynamic studies were carried out during analyses.

The Al-Si alloy drum support

The geometry of the existing drum support made of Al-Si casting alloy is shown in Figure 1 and its mass is 1128.77 grams. This geometry has been found to be topologically optimum for the Al-Si material. The support is tested in a washing machine simulation environment under quasi-static as well as dynamic combined loadings in a laboratory with specially devised testing rigs.

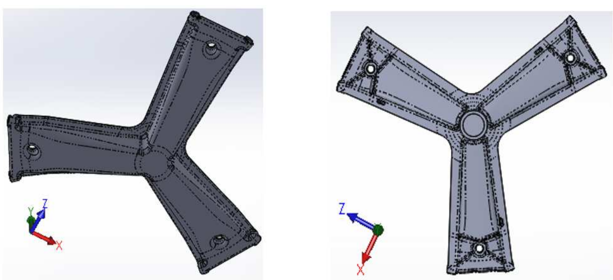

Fig. 1. Al-Si alloy drum support front and rear views

Combined quasi-static loading stress analysis for the Al-Si alloy support

This test involves subjecting a certain number of low cycles of high torque, bending moment, and shear force combined loadings [13]. 600 N·m of torque and 75 N·m of bending moment loadings were applied on the hub center of the Support. The model of the Support was discretized into a curvature-based mixed finite element mesh, where 307408 nodes and 181047 elements with side lengths varying between 1 mm and 5 mm were used, as shown in Figure 2a. The results for which the Al-Si alloy support material is assumed as linearly elastic, show a maximum 93.9 MPa safe stress value against a 160 MPa yield failure as presented in Figures 2b and 2c. The next step is to verify the safety of the support against eccentric dynamic loading.

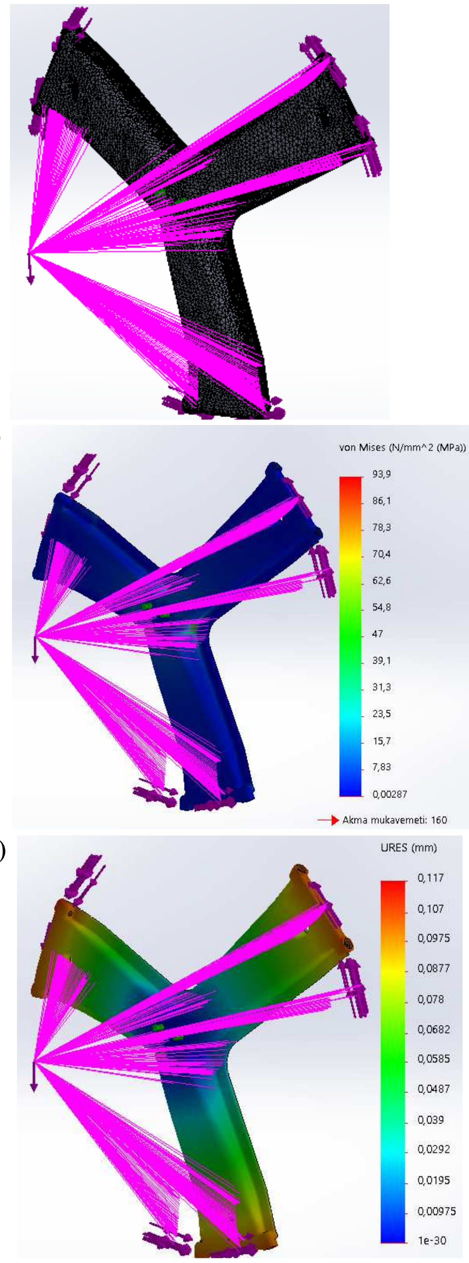

Fig. 2. Al-Si alloy support quasi-static combined loading analysis results: a) mesh and combined loadings, b) von Mises stresses, c) deformations

Combined eccentric dynamic loading stress analysis for the Al-Si alloy drum support

These tests are expected to be successfully completed for a certain number of cycles of the support under a constant angular acceleration effect with 5 different eccentric masses and angular speeds. Figures 3a-c show the isotropic elastic simulation for Al-Si support under the highest mass of 1000 gr and the corresponding lowest rotational speed of 300 rpm. The resulting maximum von Mises stress of 145 MPa means that the deformations in the material are still in the elastic region.

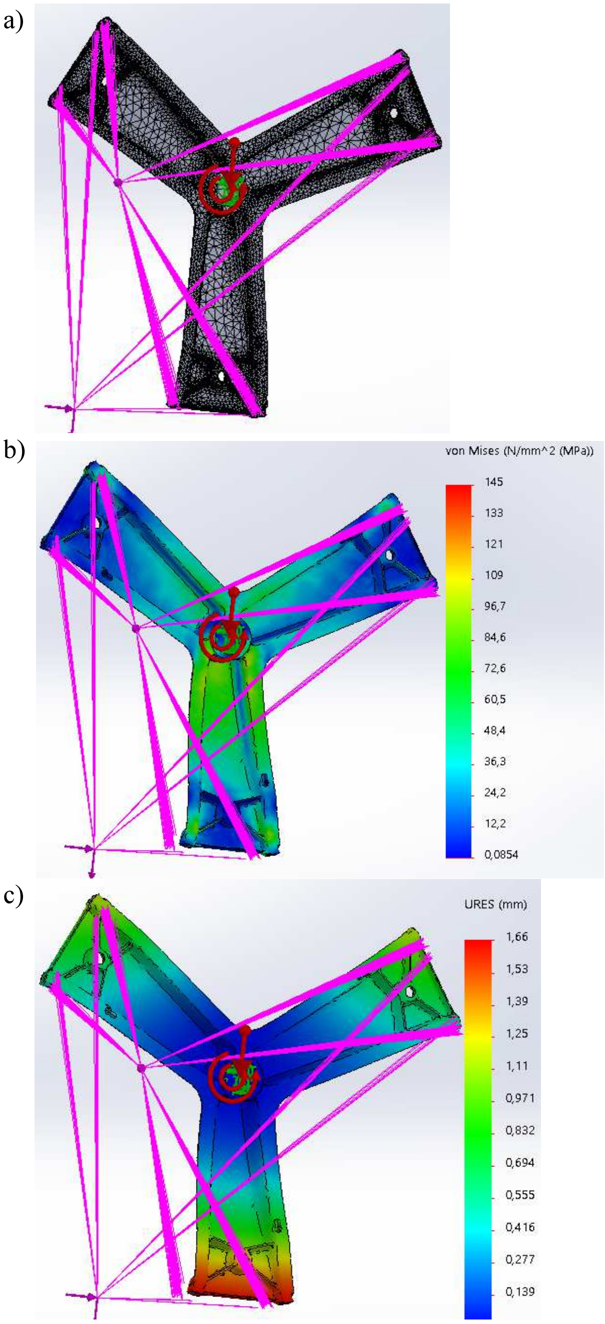

Fig. 3. Al-Si alloy support combined dynamic loading analysis results: a) mesh and combined loadings, b) von Mises stresses, c) deformations

Short glass fiber reinforced *PA+PPA* hybrid polymer matrix composite drum support

If the same geometry as in Al-Si alloy were assumed to apply for this composite, then the corresponding quasi-static von Mises stresses and deformations would be as shown in Figures 4a and 4b, respectively. The composite under consideration is assumed to follow an isotropic nonlinear elastic material behavior.

The maximum von Mises stress value of 972 MPa and the 30 mm deformation value clearly point out to the failure of the composite Support with the unmodified geometry as that of the Al-Si casting alloy. These results also show the requirement for a geometry stiffening modification if a successful material conversion from metal to composite is aimed [14, 15]. Therefore, the geometry of the composite material support has been modified with the additions of reinforcing ribs, corner, and radii treatments according to plastic part design guidelines as well as expertise and intuition. The converted geometry and symmetric half geometry of the static and dynamic analyses results of the support are depicted in Figures 5a-d. The composite material under consideration is again modelled to follow the isotropic nonlinear elastic behavior in these analyses. The solid model weight of the composite support in Figures 5a, b reduces to 768.42 gr as compared to 1128.77 gr of Al-Si support shown in Figure 1.

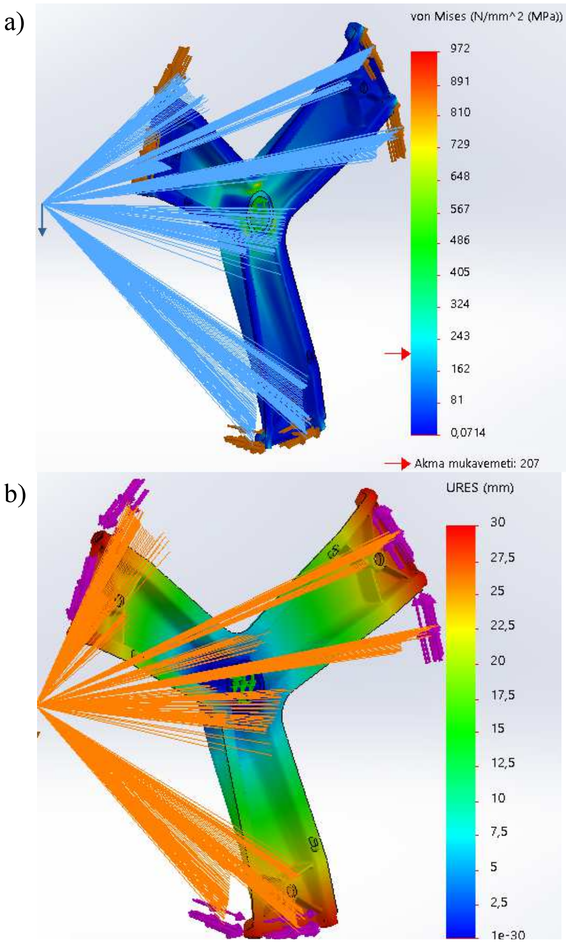

Fig. 4. Composite drum support quasi-static results with the same geometry as that of the Al-Si alloy: a) von Mises stresses, b) deformations

The maximum von Mises stresses of the quasi-static analysis in Figure 5c and that of the dynamic analysis in Figure 5d (i.e., 71.4 MPa and 186 MPa, respectively) are below the 207 MPa long-term breaking stress value of the composite material.

a)
b)
c)
d)

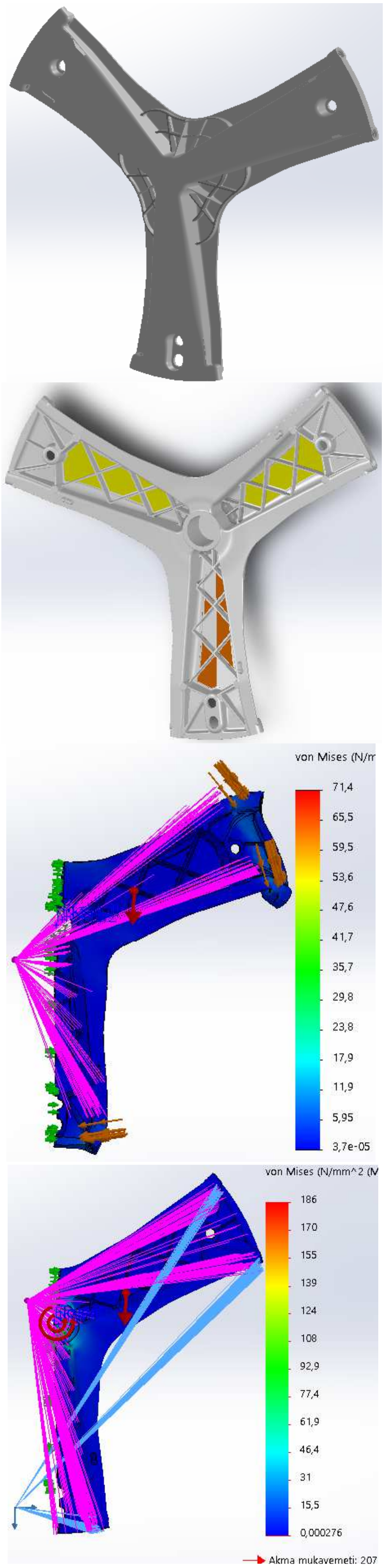

Fig. 5. Hybrid polymer matrix composite support quasi-static and dynamic analyses results with new geometry: a) front view of modified support geometry, b) rear view of modified support geometry c) quasi-static von Mises stresses, d) dynamic von Mises stresses

Topological optimization of the composite drum support

Figure 6 shows the result for 15% weight reducing topological study, which is aimed for further material removal that still gives rise to a safe performing hybrid polymer matrix composite support. The optimized geometry is disregarded for safer design reservations.

a)
b)

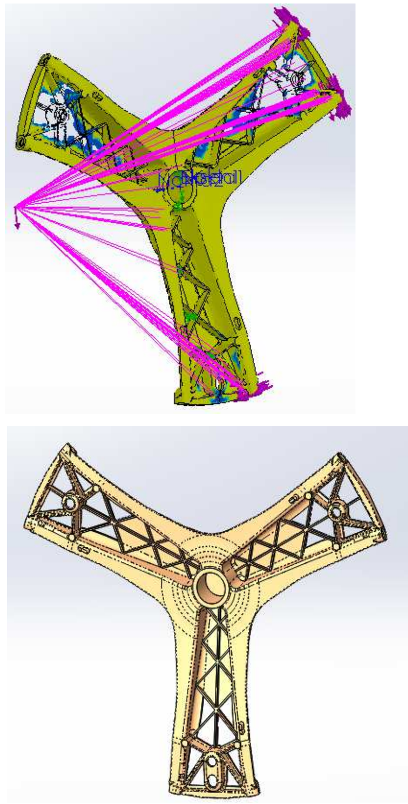

Fig. 6. Topological optimization for the composite drum support with converted geometry: a) topological optimization analysis outcome geometry, b) refined geometry of Figure 6a

PRODUCTION OF HYBRID POLYMER MATRIX COMPOSITE DRUM SUPPORT

Computer aided material conversion from an Al-Si casting alloy to a short fiber reinforced hybrid composite of the support under consideration is followed by the production of it using the injection molding process as shown in Figure 7. The weight of the injection molded composite support is 776 gr where the fixture holes were yet to be prepared.

Fig. 7. Injection molded short glass fiber reinforced PA+PPA hybrid matrix composite drum support

DISCUSSION AND CONCLUSIONS

An Al-Si cast alloy drum support is prone to oxidation due to the detergent chemicals involved during washing and to galvanic corrosion due to the steel shaft-aluminum support assembly. These effects lower the economic lifetime of a washing machine. The disadvantages mentioned here necessitate for search of alternative support materials. Composite materials, however, this time short glass fiber reinforced hybrid matrix type, have come into mind for their comparatively lower production cost and weight. For the conversion from a metal alloy to a hybrid polymer matrix composite based material of the part, not only the strength and moduli but also sectional inertial geometry must be considered. In this study, capabilities of FEM modelling have been of great help in terms of coupled analyses involving material and geometric nonlinearities as well as topological optimization. The comparison of the achieved composite part with the previous metal casting one is given in Table 2.

TABLE 2. **Comparison of using of cast Al-Si alloy and *sGf*+[*PA*+*PPA*] composite drum supports**

Cast Al-Si alloy support	sGf+[PA+PPA] composite support
200.000 Aluminum alloy pieces per steel alloy casting mold	2.000.000 pieces production per plastic injection mold
There is a glazing process cost during mold renewal	None
High customer complaints due to oxidation	None
High energy consumption due to process temperatures well above 600°C during production	Lower energy consumption during injection molding (temperatures of 360°C at most)
A weight of 1128.77 gr	Short fiber glass reinforced hybrid polymer matrix composite Support weights of 776 gr without holes
High energy consumption in washing machine due to excessive weight	Lower energy consumption in washing machine due to lower weight
Difficult to recycle	More sustainable recycling methods

This study has proved the successful use of hybrid polymer matrix composite materials for dynamically, chemically, and thermally coupled working conditions. It is also unique in that it presents the first successful design, production, and factory test rig verification of a composite drum support for a washing machine. Therefore, some technical information of the study has been omitted due to industrial confidentiality, which the authors kindly request tolerance.

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