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Material Conversion from Metal to Composite of a Washing Machine Drum Star Support and it′s Topological Optimization

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Abstract

Today, polymer composites are almost used in all areas of life. Their light weight, strength, low price and fast processing properties open new ways to their use. In this study, design and structural analysis of a short glass fiber reinforced polyamide involving drastic loadings and functioning environments is presented for a washing machine drum support. The results show that at least 50% short glass fiber reinforcement is needed for a successful material conversion from an Aluminum alloy.

Keywords: Finite element analysis • Drum support • Metal replacement • Dynamic analysis • Static analysis

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 relatively high temperatures. The earliest machines, exemplified as in Figure 1, were used as hand operated when electricity was not common [3]. A washing machine includes plastic, metal, and electronic parts. Metal parts increase the weight of a washing machine [4].

Figure 1. Types of old washing machines

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

Global competitiveness makes necessary the cost reductions of both the part and its production. In this respect, factors such as reduction of weight, cost, and energy consumption come to be important subject for research [6]. The washing machine drum rotates at a high speed of up to 1600 rpm. Apart from the perforated steel drum, reduction of the drum star weight as well as that of the main shaft can provide less energy consumption as shown in Figure 2. It has been determined beforehand that 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 star of the washing machine drive mechanism [7,8].

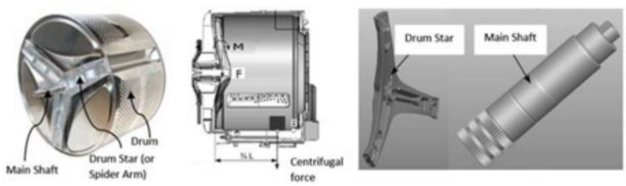

Figure 2. Drum star connection and assembly

Materials and Methods

Further cost and weight reductions leading to low energy consumption in a washing machine requires a conversion of the drum star material from aluminum based alloys to composites. Material changing of an industrial part requires evaluation of cost, strength and environmental criteria [9,10]. The interconnections among criteria are schematically shown in Figure 3, in which a redesign procedure of a part has to follow for a successful conversion [11].

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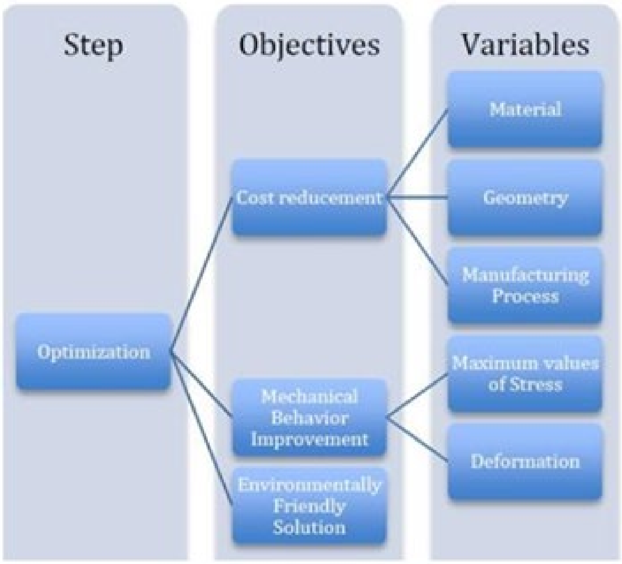

Figure 3. Redesign methodology tree

An Al alloy drum star is prone to damage due to galvanic corrosion and is produced by the costly die casting. The die casting production method includes heating 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 alloy replacement, Polyamide is widely used as a thermoplastic matrix material in composites and additions of short glass fiber reinforcement improves its mechanical properties [12]. In this study, short glass fiber reinforced polyamide composite material has been considered for replacement of the Al alloy of the drum star. The reduction in material stiffness due to conversion from an Al alloy to a polymer based composite has been remedied by geometric improvements in the varying cross sectional area of the drum star as well as by using additional supporting ribs wherever found to be necessary. Simulation premium software based static and dynamic analyses were carried out during the material conversion process for the drum star.

The Al-Si alloy based drum star

The geometry of the existing drum star made of Al-Si Casting alloy is shown in Figure 4 and its mass is 1128.77 gr. This geometry has been found to be topologically optimum for the current Al-Si material. The drum star 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.

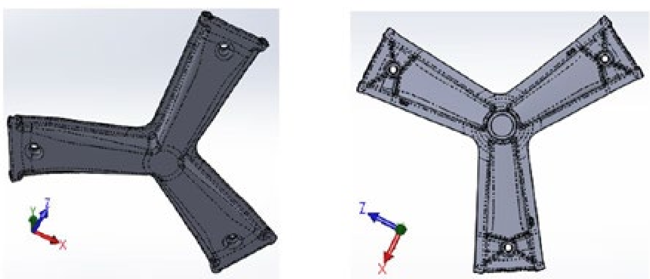

Figure 4. Al-Si Alloy drum star front and back views

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

This test involves subjecting a certain number of low cycles of high Torque, Bending Moment, and Shear Force combined loadings [13]. The results for which the Al-Si alloy drum star material is assumed as linearly elastic, show safe stress and deformation values against yield failure as presented in Figure 5. As this analysis is successful, the next step is to verify the drum star safety against eccentric dynamic loading.

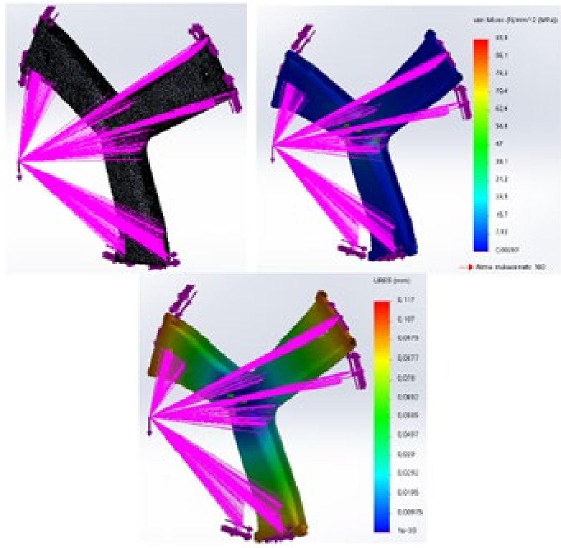

Figure 5. Al-Si Alloy drum star quasi-static combined loading analysis results

(a) Mesh and Combined Loadings (b) Von Mises stresses (c) Deformation results

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

These experiments are expected to be successfully completed for a certain number of cycles of the drum star under a constant angular acceleration effect with 5 different Eccentric Masses and Angular Speeds. Figure 6 show the isotropic elastic simulation results under the highest eccentric loading for Al-Si alloy under dynamic testing environment. The resulting maximum strain value of 4.565e-03 mm/mm (not shown) means that the deformations in the material are still in the elastic region.

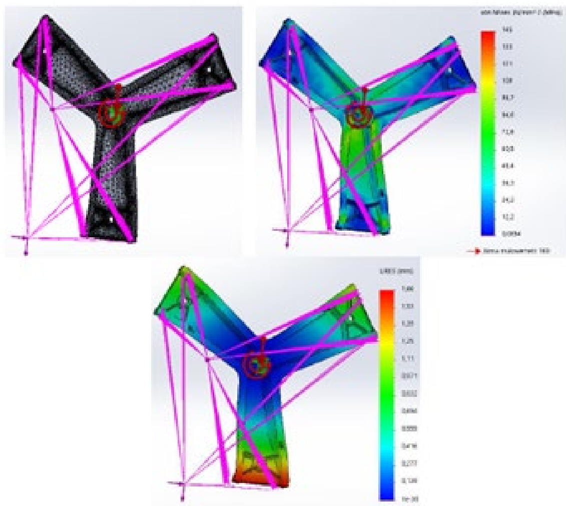

Figure 6. Al-Si Alloy drum star combined dynamic loading analysis results

(a) Mesh and Combined Loadings (b) Von Mises stresses (c) Deformation results

The short glass fiber reinforced polyamide thermoplastic composite based drum star

If the same geometry as in Al-Si alloy were assumed to apply for the short Glass Fiber Reinforced Polyamide Composite, then the corresponding quasi static von Mises stress and deformations would be as shown in Figure 7, respectively. The short fiber reinforced composite is assumed to obey the nonlinear elastic material behavior.

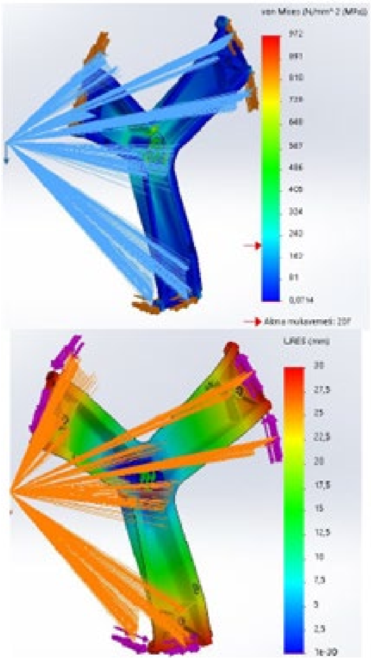

Figure 7. Composite drum star quasi-static results with unmodified geometry

(a)Von Mises stresses (b) Deformations

The maximum von Mises stress value of 864.37 MPa and the 30.776 mm deformation value clearly point out to the failure of the composite drum star with the unmodified geometry as that of the metallic one. These results also show the requirement for a geometry stiffening modification if a successful material conversion from metal to composite is aimed [14]. Therefore, the geometry of the composite material drum star has been modified with the additions of supporting ribs, corners and radii treatments according to plastic part design guidelines as well as the expertise and intuition of the authors. The converted geometry and symmetric half geometry of the static and dynamic analyses' results of the drum star are depicted in Figure 8. The Drum Star in Figure 8a has a mass of 768.42 gr. The short fiber composite material is modelled to follow the isotropic nonlinear elastic behavior in these analyses.

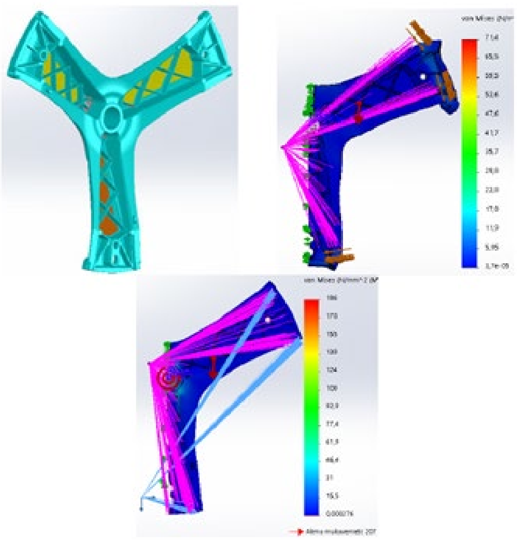

Figure 8. Composite drum star quasi-static and dynamic results with converted geometry

(a)Converted Composite Geometry (b) Quasi-static von Mises stress (c) Dynamic von Mises stress

Topological optimization of the composite drum star

Figure 9 shows the result for 15% weight reducing topological study which is aimed for further material removal that still gives rise to a safe performing drum star. The suggested geometry from the topological optimization is disregarded for safer design reservations.

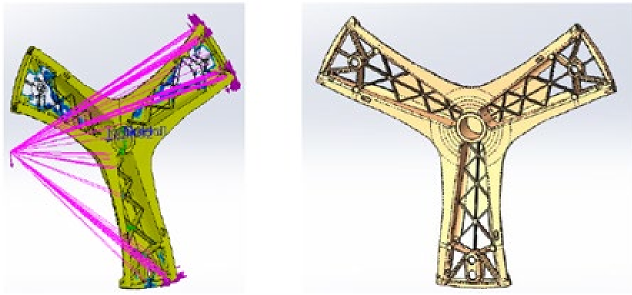

Figure 9. Topological optimization for the composite drum star with converted geometry

(a)Analysis outcome geometry (b) Refined geometry of 9a

Production of the composite drum star

Computer aided material conversion from an Al alloy to a short fiber reinforced composite of the drum star is followed by the production of it using the injection molding process as shown in Figure 10. The composite drum star has a mass of 776 gr where the insert holes were yet to be prepared.

Figure 10. Injection moulded short fiber glass reinforced polyamide composite drum

Results and Discussion

Experimental section/methods

An Aluminum drum star support is prone to oxidation due to chemicals involved during washing and to galvanic corrosion due to the steel fixtures used in assembly. These together lower the economic lifetime of a washing machine. The disadvantages mentioned here necessitates for search of alternative drum star materials. Composite materials easily come into mind for their comparatively lower production cost and weight [15]. For the conversion from aluminum to 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 aluminum casting one is given in Table 1.

Table 1. Comparison of using of aluminum and plastic drum supports

Cast Aluminium Alloy based Drum Star Support	Composite Drum Star Support
	
200.000 Aluminum alloy pieces per steel alloy casting mould	2.000.000 pieces production per plastic injection mould
There is glazing process cost during mould renewal	None
High customer complaints due to corrosion	More corrosion resistance
High energy consumption due to process temperatures well	star
above 600ºC during production	Lower energy consumption during injection moulding
(temperatures of 360ºC at most)	star
A Weight of 1128.77 gr	Short fiber glass reinforced Polyamide Composite Drum weighs 768.42 gr
High energy consumption in washing machine due to excessive weight	Lower energy consumption in washing machine due to lower weight
Difficult to recycling	More sustainable recycling methods

Conclusion

All in all, this study has proved the successful use of polymer based composite materials for dynamically, chemically, and thermally coupled conditions.

Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

Acknowledgements

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