Latin American Journal of Solids and Structures
www.lajss.org

Application of Short Fibers Reinforced Composites in Power Transmission Coupling

Abstract

In this study the use of short glass, carbon and hybrid glass-carbon fibers reinforced polymeric composites in power transmission coupling is investigated. The presented work is generalized to thermoplastic and thermoset polymeric matrix composites. The effects of the constituents weight percentages, and average fibers length on the composite tensile strength and modulus are studied using the Taguchi design of experiments method. A new approach of Finite Element analysis is introduced to model the effect of the hybrid fibers random distribution and average fibers length among the volume of the matrix. Each fiber is simulated independently in the model as a three dimensional truss element embedded in the matrix. The FEA model is applied on the tensile specimen and then on the power transmission coupling simulation. Finally, the new approach of finite element analysis results on the coupling are validated.

Keywords

Short fibers, power transmission coupling, finite element analysis

K. Hamza [a, *]
A. Y. Shash [b]
M. Abdrabou [c]

[a] Engineering & Materials Sciences Department , German University in Cairo, Egypt
kareem.abd-elwahab@guc.edu.eg
[b] Mechanical Design and Production Department, Cairo University, Giza
ahmed.shash@cu.edu.eg
[c] Mechanical Design and Production Department, Cairo University, Giza
mahmoud.abdrabou@eng.cu.edu.eg

* Corresponding author

http://dx.doi.org/10.1590/1679-78253414

Received 12.10.2016
In revised form 02.01.2017
Accepted 15.02.2017
Available online 04.03.2017

1 INTRODUCTION

Power transmission coupling and other mechanical transmission elements are usually manufactured from steel that results in relatively heavy products. In automotive, airplanes, space and other automobile applications light power transmission elements are required to reduce the energy consumption. Composite couplings provide good features including corrosion resistance, high-misalignment capacity, excellent fatigue resistance, low weight, and ease of installation (Rexnord, 2016). Fibers reinforced composites are good solutions where high properties are combined with light weight benefits. Short

Fiber reinforced thermoplastics can be used in many applications with the same manufacturing techniques used with unfilled plastics. Fibers reinforced plastics are increasingly used in plastic injected products due to their high their enhanced specific stiffness, and strength (Don Robbins, 2015). The prediction of short natural fibers composites mechanical properties is very critical and should depend on experimental work. P.J. Herrera-Franco (2005) studied the interficial properties between natural fibes and High density polyetheylene. The results showed great deviation and nonlinearity in the properties due to the many parameters affecting the interfacial bond strength. This complexity requires better simulation technique in order to reduce the required number of experiments needed to know the properties of the composite. Many studies are being conducted on studying the effect of fibers addition to polymers through pallets injection, powder injection, and compression molding. The influence of orientation of short carbon fibers in composites in powder injected composites on the shear properties is studied experimentally by Shirazi (2014) to enhance the composite properties by controlling the flow parameters in the powder injection technologies. The properties of the short fibers composites are dramatically dependent on the orientation of the fiber to the direction of the measured properties. Seyyedvahid M., and Fatemi, A., (2014) studied the anisotropy effect of the measured properties in the tensile test between the in flow direction of injection and perpendicular direction. Their results showed a significant drop in the tensile strength and modulus of the perpendicular direction compared to the in flow direction. The effect of reprocessing on fiber length distribution, tensile strength and impact strength of injection molded cellulose fiber-reinforced polylactide (PLA) composites was conducted by (Graupner, N.; Albrecht, K.; Ziegmann, G.; Enzler, H.; Müssig, J., 2016). All the conducted studies showed a dramatic effect for the fibers type, alignment, length, and processing parameters on the composite performance (Lu, 2002). This research shows a new approach of modeling the short fibers reinforced composites, where each fiber is simulated independently. The results can be visualized on the each type and segment of used fiber even with hybrid fibers composites. The problem of the available micromechanical models is the inability to accurately predict these composites' properties, performance, and durability (P. Satheesh Kumar, 2010). The available micromechanical models are not practical with 3D bulky fibers composites. The reason is that these models deal with the composite as a homogenous material with average properties (Lu, 2002). The suggested simulation technique provide practical estimates of the composite performance, and a powerful design optimization tool. The hybrid fibers percentages, inhomogeneous distribution and average length can be used as design optimization parameters. The objective of the optimizing process is to get closer to the required tensile and young's modulus values.

In this research paper, the experimental and modeling results are analyzed using the design of experiments Taguchi method. Three parameters effects are studied using 3 levels per each to present the nonlinearity and interaction effects of each parameter on the studied responses. A new Finite element model is presented to predict the composites behavior under the tensile test conditions according to the ASTM standard (D3039, 2014). Jin, BoCheng (2011) presented a 3D simulation for a representative volume element of longitudinal and random fibers reinforced composites. Kenik (2015) presented the theoretical background behind the structural FEA of fibers composite produced by the plastic injection method. Robbins (2015) used the theory of Doug and the features of Autodesk to produce random fibers distributed in injected plastics products to model biaxial loaded problems. In this research the presented finite element model is generalized to all fibers types, lengths. More researches

were conducted to check the processing parameters and effect on the product average fibers length and orientation since this will dramatically affect the properties being simulated. (Akira I., 2015) studied the effect of the screw design on the resulting average fibers length of the glass fibers injected polypropylene. The study of the processing effects on the products can be a guidance to our simulation parameters for a more validated simulation compared to the properties of experimental samples with much longer fibers. Both thermoplastic and thermoset matrices are also applicable on the model. The interaction between the fibers and the matrix is also defined. The local stresses on the fibers are recorded and the average on the composite as well. Hybrid carbon-glass fibers reinforced epoxy with the design of experiments factorial design is experimentally performed on 9 runs with 3 replications each. The same runs are also performed using the FEA model. The results of both the experimental and model runs are compared to validate the FEA model. Using the design of experiments technique, an analytical mathematical model is presented to predict the composite tensile strength and modulus as a function of the studied three parameters nonlinearly.

Finally the suggested Finite element approach is used in the simulation of a rigid coupling. The simulation loading and boundary conditions are performed based on (Rivin, 2008) guidelines for power transmission coupling design. The results are compared with the conventional isotropic simulation results. The isotropic simulation assumes isotropic homogenous properties of the coupling material. The values of these isotropic homogenous properties are got from experimental testing results using the ASTM (D3039, 2014). The two results of the power transmission coupling simulation and compared to validate the suggested new technique of fibers composites simulation. Then the presented FEA model can be used for better optimization of products made from fibers reinforced composites with lower dependence on experimental investigations.

2 EXPERIMENTAL WORK

In this section the experimental work used in studying the average fibers length and percentage on the tensile strength and modulus is reported. The procedure that will be used to study these parameters is the Taguchi design of experiments to optimize the number of experiments. The main target of the experimental work is to provide a validation for the Finite element modeling that will be discussed in section three.

2.1 Design of Experiments

In this part the methodology of studying the carbon fibers volume percentages, glass fibers volume percentage, and the average fibers length on the tensile strength and modulus is discussed. Three parameters are studied with three different levels as shown table 1. The design of experiments presented here will be followed during the modeling and the experimental testing. An L_{27}OA "27 runs orthogonal array" is required to study the three parameters with three levels. We will use a fractional factorial design with L_9OA (9 runs orthogonal array) as shown in Table 1 instead of using the full factorial design. The purpose of using the factorial design is to reduce the number of experiments while keeping a good analysis of the studied parameters effect on the tensile strength and modulus.

Level	Carbon Fibers Volume %	Glass Fibers Volume %	Average Fibers Length
1	5%	5%	5 mm
2	10%	10%	20 mm
3	20%	20%	50 mm

Table 1: Design of Experiments parameters Levels

Table 2 shows the different runs of the L_9OA results using the experimental method and the proposed model.

Run	wt. % Glass- fibers level	wt. % Carbon-fibers level	Average fibers length level
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 2: L_9OA (9 runs orthogonal array) fractional factorial design for 3 parameters and 3 levels

2.2 Tensile Testing

The tensile test was performed to each of the nine runs with three replications per each. All the runs and replications were performed in the same time under the same conditions of vacuum and processing temperature. The tensile specimen was manufactured according to the ASTM (D3039, 2014) design and guidelines. The selected specimen geometry and end taps are showed in figure 1.

Fibers were cut according to the required length using a custom fiber scissor, and then the average fibers length were measured and adjusted to the studied levels. The fibers were weighed using a 0.01 mg accuracy digital balance in order to achieve the required fibers weight percentage.

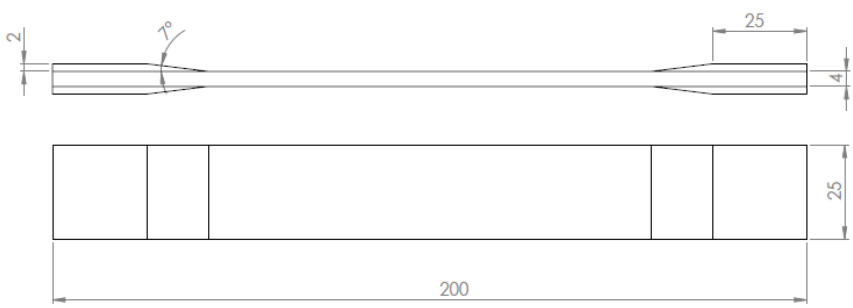


Figure 1: Tensile test specimen according to ASTM D3039.

Figure 2 shows that a two piece wooden mold was manufactured to mold the composites materials using the vacuum bagging technique in order to keep the air bubbles and voids volume less than 2% from the composite total volume.

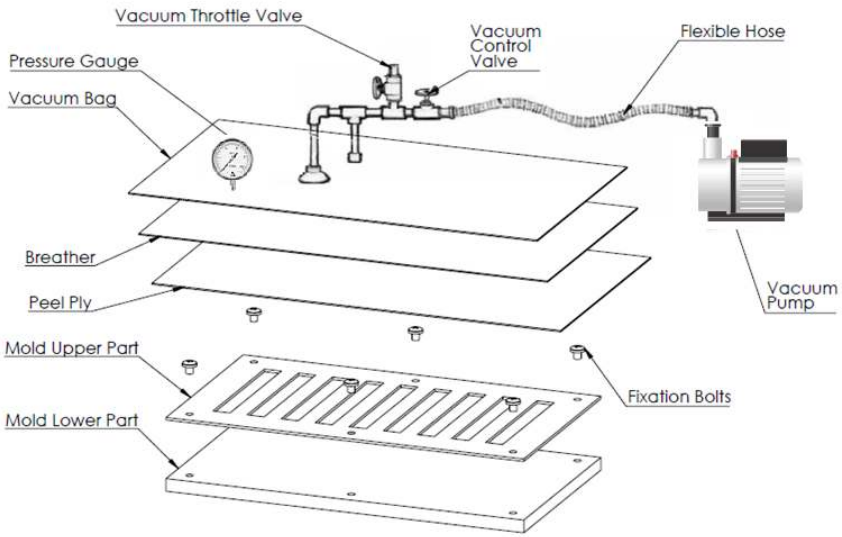


Figure 2: Vacuum bagging technique performed on the molding of the composite tensile specimen.

First, the mold was waxed with three layers of wax and a layer of polyvinyl alcohol "PVA" , then the epoxy resin components were mixed and added to the mold to fill the cavity with the fibers. The fibers and epoxy were added with random and homogenous distribution. Then, vacuum were applied according to the conventional vacuum bagging technique. A Peel Ply sheet of Nylon was added on the mold to isolate the vacuum breather and bag sheets from the composite. The vacuum pump, throttle valve, and control valve were connected to the bag. The mold was kept in a closed autoclave with 66 ^{o} C for 2 hours and then it was left for more 6 hours in the room temperature for complete curing before removing the samples. End taps of bidirectional glass reinforced epoxy were attached to the both sides of the tensile specimen. The tabs were fixed using a very thin layer of high structural epoxy adhesive and kept under the pressure of a mechanical fixture for 4 hours. Finally the samples were finished using a 120 sand paper, and cleaned using a cloth and alcohol.

3. MODELING

In this part of research a new finite element analysis approach is performed to predict the tensile strength and modulus of the studied composite. This modeling approach can also be used to get the average stresses in a 3D loaded part made of fibers reinforced matrix. The first application of the model is to create a tensile specimen with the shape and loading conditions of the ASTM D3039 standard which is used for testing fibers reinforced composites. The fibers reinforced composite is simulated by modeling the fibers and the matrix as two independent geometries. The fibers are

randomly created to fill the space of the part being modeled randomly and homogenously. The matrix is modeled as a 3D elements having the volume of the part. An embedded region interaction constraint is defined between the fibers and the matrix geometries. The fibers are the embedded region and the matrix is the hosting element.

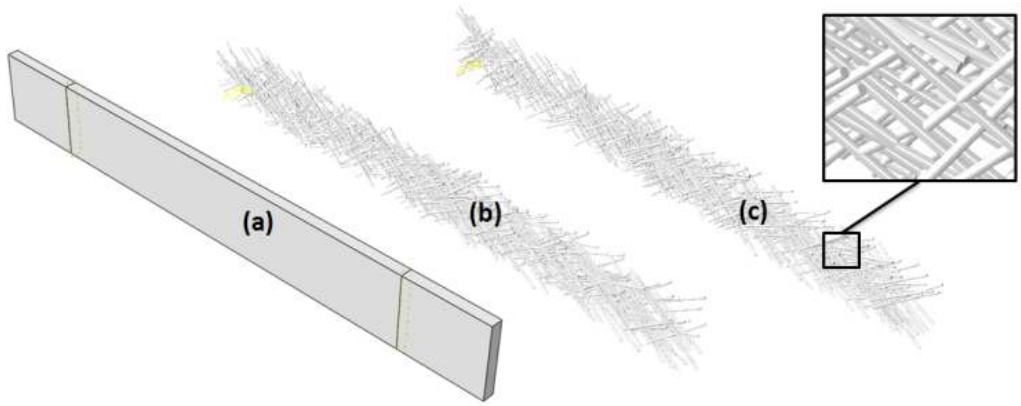


Figure 3: (a) Matrix model (b) Carbon Fibers (c) Glass Fibers, and a close view to the fibers in the FEA model.

3.1 Random Discontinuous 3D Fibers Distribution Algorithm

An algorithm is designed to create a set of short fibers in random orientations, and homogenous distribution. This algorithm can create 3D vectors having starting and ending points. It can control the average fibers length, specific or random orientation, spatial volumetric shape, and fibers volume percentage to the desired values. It can also be used with two or more fibers types. The output of the algorithm is a txt file having each vector in a single line as 6 values (X1 Y1 Z1 X2 Y2 Z2). Each vector represents a fiber in a three dimension orientation within the part X, Y, and Z limits.

The output file is then sent to Abaqus to create the required beam elements with the desired cross section and material properties. The model presented here includes carbon and glass fibers with different weight percentages according to the iteration. Each line represents a yard that consists of 100 fibers. Since the used carbon fiber diameter is 7 micrometer, so the diameter of the modeled section will be 0.7 mm. The matrix has a rectangular shape with 200x25x4 mm^3. The properties and cross sections of the two types are independent. The used element type for the matrix is a 3D general stress element. An interaction relation between the fibers and the matrix is defined through the Hashin failure condition of fibers reinforced composites. Mitchell A. Daniels (2015) also used the defined Hashin damage feature in Abaqus to predict the damage parameters in carbon fibers panels under mode III loading, and the feature showed validated results with the experimental work conducted. Mitchell's research can be a good basis to depend on this feature of the composite damage simulation. The bonding interfacial strength is defined as an interaction limiting value between the fibers and matrix. The interfacial bonding strength is calculated according to the procedure found in the mechanics of composites book (Tamuzs, 2015) and the deboning strength of fabrics with cementations matrix research conducted by Carozzi (2015).

3.2 Tensile Specimen Finite Element Analysis Model

The carbon and glass fibers were modeled as 3D truss elements with the quantity, length, and diameter that achieves the iteration parameters shown in tables 1 and 2. The matrix was simulated with 3D stress elements, and 1 mm hexagonal mesh type. The summation of the fibers and matrix volume equals the total volume of the part being simulated. The inserted materials properties of the used carbon fibers and epoxy are summarized in the table 3. The Hashin damage property of the fibers properties were also included with 70% from the ultimate tensile strength of each. Figure 4 shows that the model is divided into three regions. The 2 edges where the tabbing elements are connected to the gripper of the tensile tester. The middle part is the gauge length with 160 mm. The model is totally fixed from the left part and subjected to external displacement in the elongation direction of the specimen from 0 to 2 mm with a step of 0.05 mm/static step. The model calculates the internal reactions and stresses within the specimen and plots them with respect to the displacement, then the young's modulus can be calculates. The tensile strength can be found when the local stresses in the fibers exceeds their ultimate strength, or when the matrix stresses exceeds the interfacial bonding strength between the fibers and matrix

	Carbon Fibers Torayca T300	Glass Fibers Roblon E glass	Epoxy Epolam 2017	
Tensile Strength	3530	2000	78	MPa
Tensile Modulus	230	75	3.6	GPa
Maximum Strain	0.015	0.02	-----	
Density	1.76	2.5	1.13	g/cm^3

Table 3: Mechanical Properties of the used Carbon fibers, and Glass Fibers (Axson, 2005) (Roblon, 2012) (Toryaca, 2016).



Figure 4: FEA Tensile Test Loading and boundary conditions.

3.3 Rigid Power Transmission Coupling Finite Element Analysis Model

The new technique of fibers reinforced plastics composites will be used here to simulate random short fibers reinforced in a 3D bulky matrix. A rigid power transmission coupling is selected due to the need for replacing steel and other conventional heavy materials. The rigid coupling is designed according to Rivin (2008) guidelines of power transmission coupling design. The loading and stresses provided by the guidelines are also used in the simulation procedure. The design of the coupling is performed on a shaft diameter of 30 mm from both sides.

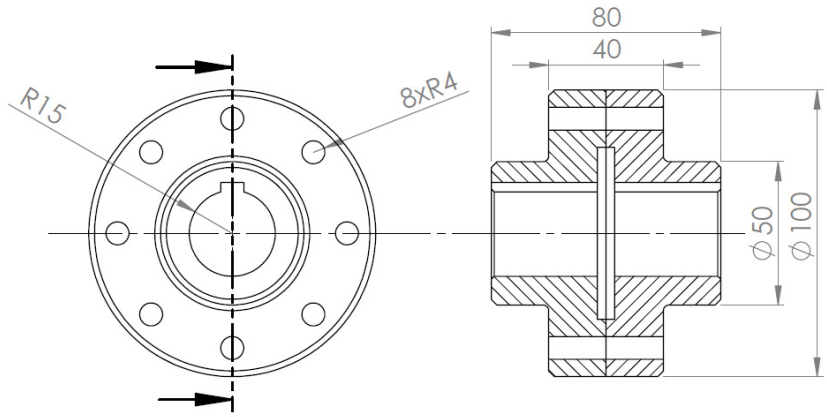


Figure 5: Studied Rigid Power Transmission Coupling Design.

The new technique of simulation will be performed using an algorithm that will create 3D random distributed fibers that fills the volume of the designed coupling as shown in figure 6. The algorithm sticks the average fibers length to 20 mm, and the number of fibers to meet the volume fraction to 20% from the total volume of the coupling. The algorithm goals are to achieve random orientations with homogenous distribution that is similar to what can be got from molding such a shape. The fibers were uniformly distributed in all the parts of the coupling since the algorithm creates random uniform distribution values for the starting points of the fibers vectors. The algorithm also uses a uniform random orientation angles with the x, y, and z directions.

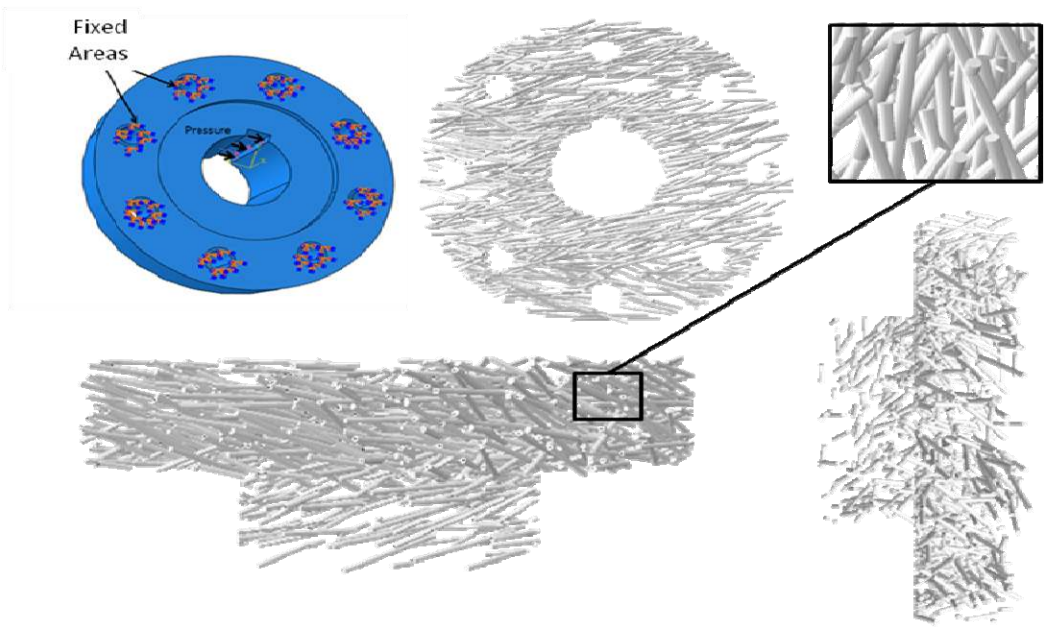


Figure 6: Coupling Loading and boundary condition, and the fibers distribution along the coupling volume.

One part of the coupling is simulated using two assembled parts: The first is the matrix that has the complete volume of the coupling part, and the second is the fibers that are embedded within the matrix. The embedded region interaction is defined in Abaqus to remove the intersection volume of the fibers with the matrix from the matrix volume, and create the interaction between them with the bonding strength values. These values are calculated based on the fibers and matrix properties according to the failure criteria discussed in the mechanics of composites book (Tamuzs, 2015) and by Carozzi (2015). The coupling are fixed at the effective area around the bolts holes on the friction sides of the coupling and the load is defined as a pressure on the keyway face as shown in figure 6.

Figure 6 also shows the uniform random distribution of the fibers within the coupling volume. The algorithm enables us to control the fibers distribution in different areas. In the slender areas, the fibers average length is lower than other areas. This reflects the difficulty of reaching all the fibers to the slender and far areas in the manufacturing process.

4 RESULTS

In this section the results of the experimental testing and the finite element model of the tensile specimen are reported and discussed. A micromechanical model correction to the rule of mixture is introduced to predict the tensile strength and young's modulus of the composite. Finally, the results of the coupling simulation are reported.

4.1. Tensile Testing Results and Analysis

The results of the tensile testing of the 9 different runs with their three replications are listed in table 4.

Run	Young's Modulus (GPa)				Tensile Strength (MPa)			
	Rep. 1	Rep. 2	Rep. 3	Average	Rep. 1	Rep. 2	Rep. 3	Average
1	7.61	7.12	7.9	7.5	60.1	58.1	59.2	59.1
2	12.1	12.5	12.7	12.4	135.8	132.5	127.1	131.9
3	25.4	24.8	22.5	24.2	305.8	314.9	310.8	310.5
4	8.8	8.81	8.5	8.7	117.9	113.6	115.9	115.8
5	14.9	15.3	15.2	15.1	211.7	210.9	208.9	210.5
6	20.1	21.3	21.9	21.1	181.9	192.4	182.5	185.6
7	14.6	18.5	15.6	16.2	209.9	211.7	210.9	210.8
8	13.8	14.7	13.9	14.1	150.8	146	149.1	148.6
9	26.5	25.8	26.1	26.1	301.2	294.8	299.5	298.5

Table 4: Tensile Testing results of the 9 runs/ 3 replications.

The design of experiments is performed to study the statistical significance of the three studied variable: weight percentage of the glass and carbon fibers in addition to the average fibers length. The following tables show the significance of the variables on the two studied responses at 90% and 95%

confidence levels by comparing them with the corresponding standards F-test values. Table 5 shows the process of the design of experiments where the statistical sums, variance, and F-test values.

Variable	Statistical Sum		Degree of Freedom	Variance		F-Test	
	Elastic Modulus	Tensile Strength		Elastic Modulus	Tensile Strength	Elastic Modulus	Tensile Strength
Glass Fibers wt%	31.6	5098.3	2	15.79	2549.17	25.42	12.07
Carbon Fibers wt%	277.1	30051.1	2	138.54	15025.6	223.05	71.14
Average Fibers Length	28.1	19156.4	2	14.05	9578.22	22.63	45.35
Error	1.2	422.4	2	0.62	211.21	--	--
Total	338	54728.4	8	--	--	--	--

Table 5: Testing Results Design of Experiments Parameters Study and significance Test (F-Test).

Variable	90% Confidence Level		95% Confidence Level	
	Elastic Modulus	Tensile Strength	Elastic Modulus	Tensile Strength
Glass Fibers Wt%	Yes	Yes	Yes	No
Carbon Fibers Wt%	Yes	Yes	Yes	Yes
Average Fibers Length	Yes	Yes	No	Yes

Table 6: Significance (F-Test) Results on the studied parameters with 90% & 95% Confidence levels.

4.2 Finite Element Analysis of the Tensile Specimen Results

In this section the new finite element analysis method presented in the previous section will be used on the 9 runs of the design of experiments suggested in the second section. The young's modulus and tensile strength will be calculated. Table 7 shows a comparison between the experimental and the FEA model tensile strength and modulus results. The young's modulus got from the model is 19% higher than the experimental results. The model tensile strength is 2% higher than the experimental results.

Run	Young's Modulus (GPa)		Tensile Strength (MPa)	
	Experimental	FEA Model	Experimental	FEA Model
1	7.5	6.7	59.1	66.5
2	12.4	14.3	131.9	185
3	24.2	32.4	310.5	405.6
4	8.7	10.2	115.8	158.9
5	15.1	19.8	210.5	312
6	21.1	21.3	185.6	217
7	16.2	16	210.8	285.6
8	14.1	14.4	148.6	183
9	26.1	31.1	298.5	385.6

Table 7: Comparison between the tension test results and the FEA model.

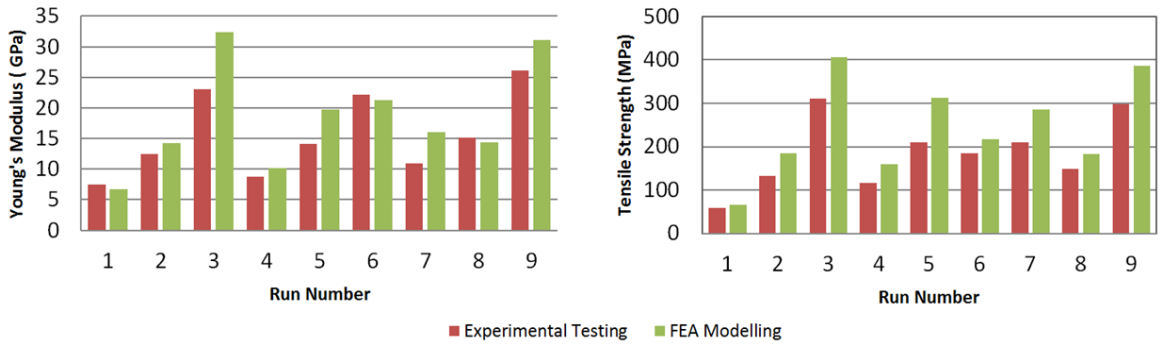


Figure 7: Comparison between the results of the tensile specimen experimental testing and FEA model.

The FEA model gives higher strength and young's modulus as it neglects the presence of air voids, and it assumes also unique fibers length without processing breakage problems. The ratio between the model and experimental results depends on the manufacturing technique and average fibers length. There is also a remarkable difference between the FEA model and the experimental results at runs 3, 5, and 7. These three runs average fibers length is the highest levels with 50 mm. This means that the increase of the fibers length deviate the results of the suggested model from the experimental results,

The following table shows the process of the design of experiments where the statistical sums, variance, and F-test values.

FEA Model Validation with the Experimental Results

Here we will model tensile strength and young's modulus as a function of its constituent's properties and weight percentages as follows:

$$E = K_{GE}\, E_G\, W_G + K_{CE}\, E_C\, W_C + K_{ME}\, E_M\, (1 - W_G - W_C) \tag{1}$$

$$\sigma = K_{GS}\, \sigma_G\, W_G + K_{CS}\, \sigma_C\, W_C + K_{MS}\, \sigma_M\, (1 - W_G - W_C) \tag{2}$$

Where:

E, E_G, E_C, E_M : Composite, glass fibers, carbon fibers, and matrix moduli of elasticity

σ, σ_G, σ_C , σ_M : Composite, glass Fibers, carbon fibers, and matrix moduli of elasticity

K_{GE} , K_{CE} , K_{ME} : Glass Fibers, Carbon Fibers, and matrix modulus of Elasticity factor

K_{GS} ,K_{CS} ,K_{MS} : Glass, Carbon, and matrix Tensile strength factor

W_C, W_G : Carbon fibers and glass fibers weight percentages

The effect of the average fibers length and the processing factors will be included into the equation as follows:

$$E = K_{SE}\, K_{LE}\, L^a (K_{GE}\, E_G\, W_G + K_{CE}\, E_C\, W_C + K_{ME}\, E_M\, (1 - W_G - W_C) \tag{3}$$

$$\sigma = K_{SS}\, K_{LS}\, L^b (K_{GS}\, \sigma_G\, W_G + K_{CS}\, \sigma_C\, W_C + K_{MS}\, \sigma_M\, (1 - W_G - W_C) \tag{4}$$

Where:

K_{SE} and K_{SS} are the model correction numbers,

K_{LE}, and K_{LS} are the average fibers length factors,

a,b are the average fiber length exponent.

The 9 runs of the FEA model are used to get the K_{GE} ,K_{CE} , K_{ME} , K_{GS} ,K_{CS} ,K_{MS}, K_{LE}, and K_{LS} ,a, and b. The experimental results were also used to calculate the FEA model correction numbers: K_{SE} and K_{SS}. The model correction numbers are mainly depended on the manufacturing process, so the will vary if the composite is manufactured through the injection or compression molding techniques. Injection and compression molding will create a preferred direction for the fibers in the injection direction and on the outer surface. The factors values were calculated by comparing the experimental results with the model outputs and they are listed below in table 8.

Elastic modulus validation		
Carbon fibers factor	K_{CE}	0.516
Glass fibers factor	K_{GE}	0.304
Matrix factor	K_{ME}	0.718
length factor	K_{LE}	0.982
length exponent	a	0.004
Processing factor	K_{SE}	0.85
Tensile strength validation		
Carbon fibers factor	K_{CS}	0.349
Glass fibers factor	K_{GS}	0.283
Matrix factor	K_{MS}	0.796
length factor	K_{LS}	0.937
length exponent	b	0.024
Processing factor	K_{SS}	0.8

Table 8: Parameters and constants values used in the modified rule of mixture.

4.3. Power Transmission Coupling FEA Modeling Results

The coupling model was loaded with two different models: Model (1) where the material was defined as an isotropic material having the properties calculated from equations of the previous section; Model (2) where the coupling was modeled as a composite material of fibers as 3D truss elements within the matrix 3D stress elements. The results of the two models at 100 N.m torque are shown below in figure 8.

The two models were loaded with different torques from20 N.m up to 200 N.m. The same idealization technique, boundary condition, and loads were added to the two models for a practical comparison. The maximum von Mises stresses in the composites, maximum local Mises stresses in the fibers, and deflection for both models were reordered and listed below in table 9, and figure 9.

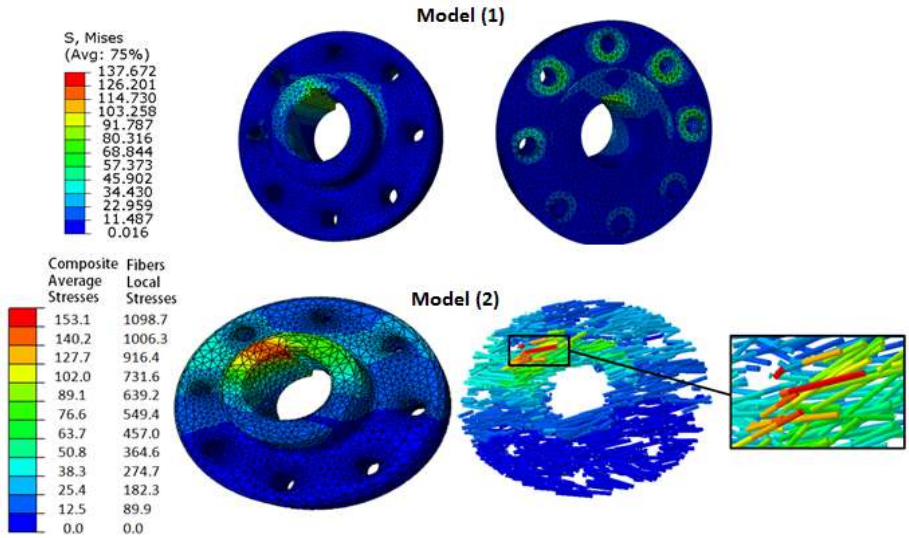


Figure 8: Mises Stresses distribution loaded with 100 N.m Torque, for Model (1) at the top, and Model (2) at the bottom of the figure.

Torque (N.m)	Mises Stresses (Mpa)			Deflection (mm)	
	Composite Model	Fibers Local Stress	Isotropic Model	Composite Model	Isotropic Model
20	32.5	192.3	27.5	0.012	0.009
40	64.3	395.5	54.9	0.025	0.017
60	95.7	618	82.4	0.037	0.026
80	126.6	857	109.9	0.049	0.035
100	153	1098.7	137.3	0.062	0.044
120	180.9	1318.4	164.8	0.074	0.052
140	211.1	1615	192.3	0.086	0.061
160	240.5	1845.8	219.7	0.099	0.07
180	269.8	2101.2	247.2	0.111	0.079
200	299.8	2334.7	274.7	0.123	0.087

Table 9: FEA Model (1) and (2) Results of the power transmission Coupling.

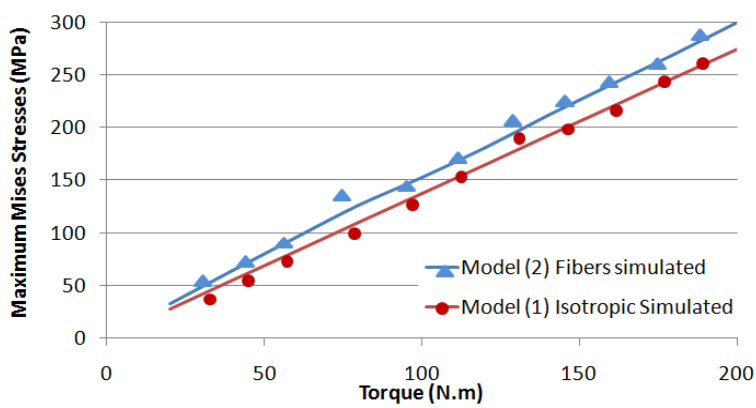


Figure 9: Maximum Mises Stresses in the coupling relation with the applied torque using the two FEA models.

5. CONCLUSION

Short fibers reinforced composite materials can be modeled where the random fibers are simulated as three dimensional random distributed truss elements embedded in a 3D solid homogenous matrix. The model is generalized for thermoplastics and thermosets. The model can be applied on the tensile test specimen to estimate the tensile strength and modulus of the composite material. The model can also be applied on rigid power transmission coupling design to estimate the maximum average stresses on the composite and maximum local stresses on the fibers. The results from the models were validated using tensile testing according to the taguchi L9OA design. A modification to the rule of mixture has been introduced with 1.1% mean square error from the experimental results. The suggested modified rule of mixture includes the constituent's properties, percentages, average fibers lengths, modeling, and processing parameters. Hybrid glass – carbon fibers reinforced composites can be used in power transmission coupling, and maximum permissible torque and speed can be predicted with 5% uncertainty using the suggested approach of modeling. The proposed FEA model can be used to:

1. Reduce the number of experiments performed in finding accurate composite properties.
2. Optimize the fibers type, length, orientation, and concentration on any 3D bulky shape.
3. Predict the failure of any bulky 3D design due to local and interfacial stresses within the composite.

Randomness and homogeneity of fibers distribution could be controlled using the uniform random distribution algorithm. This could reflect the real distribution predicted from the manufacturing nature. More work is needed in order to predict the effect of the processing technique on the fibers distribution and homogeneity.

References

Akira I., K. M. (2015). Effect of screw design on fiber breakage and dispersion in injection-molded long glass-fiber-reinforced polypropylene. Journal of Composite Materials, 75-84.

Carozzi, F. G. (2015). Mechanical properties and debonding strength of Fabric Reinforced Cementitious Matrix (FRCM) systems for masonry strengthening, Composites Part B : Engineering, 215–230.

D3039, A. ,2014. ASTM D3039 / D3039M-14, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM International, West Conshohocken, PA, 2014.

Don Robbins, A. M., (2015). Progressive failure simulation of as-manufactured short fiber filled injection molded parts: validation for complex geometries and combined load conditions. Autodesk, Inc Society of Plastics, Automotive Composite Conference.

Doug Kenik, D. R., (2015). Bridging the gap: as-manufactured structural simulation of injection molded plastics. Spacce conference automotive division. Laramie wy, usa: Autodesk Inc.

Graupner, N., Albrecht, K., Ziegmann, G., Enzler, H., Müssig, J., (2016). Influence of reprocessing on fibre length distribution, tensile strength and impact strength of injection moulded cellulose fibre-reinforced polylactide (PLA) composites. Express Polymer Letters . 2016, Vol. 10 Issue 8.

Herrera-Franco, A. V.-G. (2005). A study of the mechanical properties of short natural-fiber. Composite part B engineering, 597-608.

Irfan Shirazi, F. A., (2014). Shear controlled alignment of short carbon fibers in copper matrix composite green samples produced by powder injection molding. Tronoh, Malaysia: AIP conference.

Jin, BoCheng. (2011) 3-D Numerical simulation and analysis of complex fiber geometry RaFC materials with high volume fraction and high aspect ratio based on ABAQUS PYTHON. New Jersey, USA: the state university of New Jersey, Mechanical and Aerospace Engineering.

Lu, Y., (2002) Mechanical properties of random discontinuous fiber composites manufactured from wetlay process. Blacksburg, Virginia: Faculty of the Virginia Polytechnic Institute and State University.

Mitchell A. Daniels, L. J. (2015). Effects of Finite Element Damage Modeling Parameters in Carbon Fiber Panels Under Mode III Loading. ASME 2015 International Mechanical Engineering Congress and Exposition (pp. ISBN: 978-0-7918-5752-6). Houston, Texas, USA, November 13–19, 2015: ASME.

Rexnord. (2016). Addax composite couplings. Retrieved from Rexnord Cooperation: http://www.rexnord.com/ContentItems/TechLibrary/Documents/2022_Addax-Composite-Couplings_Catalog-pdf

Rivin, E. I. (2008). Selection and Performance Criteria for Power Transmission Couplings. Retrieved May 8, 2015, from Power Transmission Engineering: www.powertransmission.com

Satheesh Kumar, P., Srikari, S., Mahesh, N. S., Reddy, S., (2010). Structural analysis of fiber- filled plastics. Sastech journal, 9(2).

Seyyedvahid Mortazavian, A. F. (2014). Effects of Fiber Orientation and Anisotropy on Tensile Strength and Elastic Modulus of Short Fiber Reinforced Polymer Composites. Composites part B engineering, 116-129.

Tamuzs, V. P. (2015). Mechanics of Composite Materials. 1(6).

Axson, (2005), Epolam 2017 system, Retrieved on May 8 , 2015, from Axson technologies :http://www.axson-technologies.com/en/Find-product.

Roblon. (2012). Roblon Products. Retrieved May 8, 2015, from Roblon: http://www.roblon.com/en/business_system/

Toryaca. (2016). Torayaca Cloth. Retrieved May 8, 2016, from Toray Innovatiob by technology: http://www.torayca.com/en/download/pdf/cloth.pdf