International Journal of Civil Engineering and Technology (IJCIET)
Volume 9, Issue 13, December 2018, pp. 199-206, Article ID: IJCIET_09_13_022
Available online at http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=13
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

NUMERICAL AND EXPERIMENTAL INVESTIGATION OF FUNCTIONALLY GRADED RUBBER-NANO-COMPOSITE CORE FOR SANDWICH STRUCTURE

Ahmed Fadhil, Ammar Al-Kawaz and Ahmed Ehsan
College of Materials Engineering / Department of Engineering of Polymer and Petrochemical Industries, University of Babylon, Iraq.

ABSTRACT

Sandwich plate is utilized in an assortment of engineering enforcements such as flying machine, building, and transport, which the solid, firm and light structures are required. If the sandwich contains a functionally graded core, which can spread the stresses that caused by bending or by the dynamic assimilation of energy that caused by impact loading, and consequently, the materialness of sandwiches could be enhanced. The current research is an attempt to numerically using finite element and experimentally investigate of flexural and impact behaviour of functionally graded rubber reinforced with different ratio of Wollastonite filler as core in sandwich composite as well as epoxy resin reinforced with carbon fibers serves as a skin in sandwich structure. Rubber core consists of five layers with weight fraction of Wollastonite (0, 1, 2, 4 and 8) from the top to the base respectively, while the skins are epoxy reinforced with carbon fibers unidirectional and chopped with (50%) volume fraction. Tests performed include flexural resistance, impact resistance and rheological properties for core. The results show good agreement between finite element analyses and experimental, while the bending strength and impact strength for unidirectional reinforcement skin shows higher value than chopped case, furthermore, it was found that the strength values have increased significantly for the proposed structure compared to the conventional sandwich structure while maintaining the weight of the structure.

Key Words: Sandwich penal, functionally graded materials, Flexural behavior, ANSYS

Cite this Article: Ahmed Fadhil, Ammar Al-Kawaz and Ahmed Ehsan, Numerical and Experimental Investigation of Functionally Graded Rubber-Nano-Composite Core for Sandwich Structure, International Journal of Civil Engineering and Technology, 9(13), 2018, pp. 199–206

http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=9&IType=13

1. INTRODUCTION

Sandwich-organized composites are an exceptional class of composite materials, created by joining two thin however solid skins to a lightweight, yet the thick core. These materials have progressively been utilized in an assortment of modern applications, for example, marine, car industry, aeronautics, and aerospace as it is convenient for designers to design for specific requirements with precision and work with the desired characteristics, due to high strength to weight ratios [1].

Pristine metals are of little use in building applications in light of the request of clashing property necessity. The composite material with special physical and chemical properties is a type of developed material which synthetic from one or more materials integrated into solid states. The composite material offers a phenomenal blend of properties, which are unique in relation to the individual parent materials and are likewise lighter in weight. Under extreme working conditions, most of the composite materials will fail by delamination mode (separation of fibres from the matrix) [5]. This can occur for instance, in a high-temperature application especially when utilized two metals having a different coefficient of expansion. A novel material called Functionally Graded Material (FGM) is being utilized to solve this issue[2].

Functionally graded materials (FGM) are composites where the composition varies from place to place in order to affect the best performance of the structure. The development of FGM has demonstrated its possible uses in a wide range of thermal and structural applications such as thermal barrier coatings, corrosion and wear resistant coatings and metal/ceramic joining. Mechanical properties gradation offers ways of optimizing the structure and achieving high performance and material efficiency. At the same time, this optimization can result in numerous mechanical problems including estimation of effective properties and crack propagation behaviours in the final structure[3][4].

Among the several structural constructions, and, in view of its exceptional twisting inflexibility, low particular weight, magnificent vibration qualities and great good fatigue properties, the sandwich kinds of structures are usually utilized in the aviation vehicles. Laminated composite types of constructions are, as a rule, adopted in sandwich structures[5]. Sandwich structures include of composite or isotropic facades propped by foam or the core of honey As well, classical cores, new systems such as truss-reinforced cores have been taken into consideration[6]. To accomplishing strong, hardened and light-weight structures in building, Sandwich developments are widely utilized [7].

M.S Kirugulige et al (2005), they examined the capacity to expand the implication of FG by employing synthetic foams as a core material for the sandwich body and investigating the resulting usefulnesses and the elastic depiction of synthetic foam core materials are qualified. In addition, they effectively utilized Finite element models to catch the experimental responses up to crack initiation. Employing these models, the function of several elastic strength gradients in the core material for two-cracked sandwich structural geometries with mixed-mode, face-sheet/core cracks are tested. Computations recommend improved crack execution of graded sandwich structures when compared to a traditional counterpart under stress-wave stacking conditions[7].

M R DODDAMANI and S M KULKARNI (2010), they prepared and testing of sandwiches with FG core in flatwise compression. They used weighting method to estimate the gradation in the core.

M. Doddamani et al (2012), they used three-point bending behavior to examine the sandwich composites beam made out elastomer reinforced with fly ash cores and epoxy shells. the differential settling of these particles causes the gradation in the core and they demonstrated that the particular modulus diminishes as the filler content increased or the orientation is varied and increments with the proportion of the core thickness to the thickness of the full beam[8]. V. Birman &N. Vo (2017), displayed an examination of corrugating in sandwich structures with functionally graded cores. Two models of grading are considered, where, a ceaselessly alter the stiffness of the core and the core consisting of several layers, every layer has own stiffness. They demonstrated that an attractive increment of the corrugated stress may be accomplished utilizing thin layers of a stiffer core adjoining to the surface[9].

S. Mohammad and F. Abdi (2012), they prepared functionally graded materials (FGM) using sulfur concrete and rubber and they showed that the physical and mechanical properties of sulfur concrete and rubber were changed continuously over the thickness. They noted that, with changing some parameters such as the percentage of the gradient of FGM or thickness layers, FGM could be optimized[10].

In this work, a numerically (by using ANSYS) and experimentally methods were used to investigate of flexural and impact the behaviour of functionally graded rubber reinforced with different ratio of Wollastonite as a core in the sandwich composite as well as epoxy resin reinforced with carbon fibres serves as a skin in the sandwich structure.

2. EXPERIMENTAL WORK

2.1. Materials

The matrix phase is blende of NBR and SBR rubber (50/50) supplied by Babel Company for the tire industry, Wollastonite was purchased from (Alibaba company) have the general composition are found by XRF test was (wt. %): “SiO_2, 57.72; CaO, 34.1; MgO, 2.4997; Al_2O_3, 0.1217; P_2O_5, 0.025; K_2O, 0.0378; Cr_2O_3, 0.0345; Fe_2O_3, 0.01106; NiO, 0.0177; CuO, 0.0093, SrO, 0.0546; ZrO_2, 0.0081”. The wollastonite is a naturally occurring raw material were obtained from (Guangzhou billion peak chemical technology Co., Ltd. and have a general properties in table (1).

Table 1: General properties of Wollastonite

Colour	PH	Brightness	Particle Shape	Hardness	Density	Ref Index	Oil Absorption
White	9.9	85-93	Needles (L/D = 3 – 20:1)	4-5 Mohs	2,94 g/cm^3	1,63	15 – 45 g/100g

2.2. Preparation (FGM)

For processing of FG core, a five rubber composite layers prepared using laboratory mill roller at 70^{o}C, every layer of the core have been reinforced with various ratios of wollastonite (0, 1,2, 4 and 8 pphr) and with fixed percent for other ingredients, table (2).

Table 2: The compositions of FG core layers

Compounding Ingredients(pphr)	(1)	(2)	(3)	(4)	(5)
NR/SBR(50/50)	100	100	100	100	100
ZnO	3.6	3.6	3.6	3.6	3.6
Stric Acide	1.8	1.8	1.8	1.8	1.8
Silver	3	3	3	3	3
MBT	0.5	0.5	0.5	0.5	0.5
MBTS	0.5	0.5	0.5	0.5	0.5
Wollastonite	0	1	2	4	8

As mentions the skins of sandwich, a mat of carbon fabric. This parts of fibers are cut into two layers with dimensions 15 cm, 15 cm. The thickness of layer is 0.5 mm and then immersing the carbon mat in epoxy resin (Bisphenol A), finally, the hardener was added to complete curing the skin at 100 ^{o}C for 4 hr. FG core prepared by the earlier mentioned procedure is glued with the two prepared skins. The final product shown in figure (1).

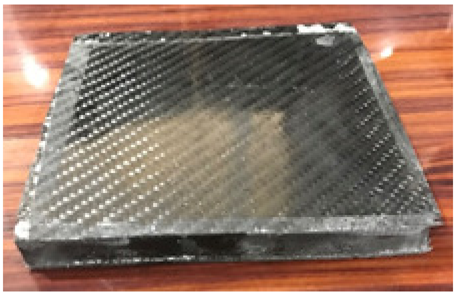

Figure 1 Prepared sandwich structure

2.3. Characterization

2.3.1. Rheological properties of the core layers

The rheological properties have been tested using Oscillating Disk Rheometer (ORD) according to ASTM D-2084[11]. Where the sample is placed inside a closed gap and after one minute of closing the gap, the metallic disc will be immersed in the hot sample. The oscillation of the disc at a constant frequency (Hz 1.6) and a constant capacity (degree 0.03 ± 1) around the center point and along the length of a small arc. This device can track the three stages of vulcanization and provide us the specifications of the vulcanization (ts_2, t_{90}, and $_{M}H$), table (3) show the summery of rheological behavior of core layers.

Table 3: Curing behavior of wollastonite filled rubber blend (NR/SBR) compounds

N. of sample	W% Wollastonite	M_L (Ib.in)	M_H (Ib.in)	Induction Period(ts_2) min	Curing Period(t_{90})min	Poisson's ratio(υ)	Elastic Modulus(MPa)
S1	0	5	26.1	3.27	6.57	0.44	14
S2	1	5.1	27.3	3.33	6.5	0.44	23
S3	2	5.2	26.3	3.35	6.67	0.44	27
S4	4	4.6	26.9	3.3	6.53	0.44	34
S5	8	4.5	28.8	3.17	6.7	0.433	40

The curing attributes of rubber filled by wollastonite matrix are exhibited in Table 3. The maximum torque growing with increasing fillers loading. The augmentation in the greatest torque esteems demonstrates that the nearness of fillers in the mixes have a tendency to diminish the portability and suppleness of the macromolecular chains of the matrix. Modulus fundamentally expanded with rising the stacking of wollastonite, this shows the present of wollastonite that can decrease the flexibility of the rubber chains.

2.3.2. Numerical Modeling:

The Finite Elements demonstrate models the ingredients of the functionally graded core and their sandwiches to ponder the associations of these in stack exchange and instruments affecting their fail. To comprehend and foresee the impact of material and in addition geometrical parameters on the mechanical conduct of Functionally Graded of wollastonite filled elastic composites and their sandwiches finite element investigation might be an exceptionally successful strategy. Towards this, a straightforward discretized pattern is a construct (ANSYS 16) appearing to FG composites with properties contrasting from a top layer to base appearing to graduate.

In this analysis, a three dimensional model of a FG system as shown in figure (2) is built and meshed with 8-node SOLID186 element. The default mesh size is selected.

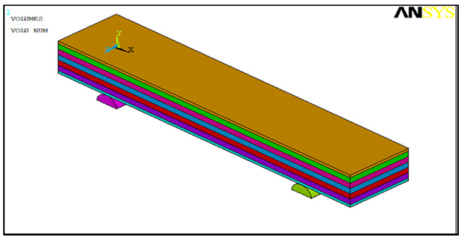

Figure 2 Three-dimensional model of FG system

Finite element amounts are contrasted and test ones for flexural conduct of functionally graded sandwich. At the connection area of the layers and amongst layers and skins of sandwich glue stipulations are connected to prevent genealogical development of layers with deference of each other. Moreover, the nodes are integrated at the interface permitting appropriate coupling amongst layers and interfaces. Figure (3) indicates FE model with boundary conditions as a standard status deem for three-point bending investigation, a rectangular plate with dimensions of (150×30)mm and thickness of (18) mm (each layer of rubber with 3 mm and skin 1.5 mm) with number of nodes (3875) and number of elements (2854).

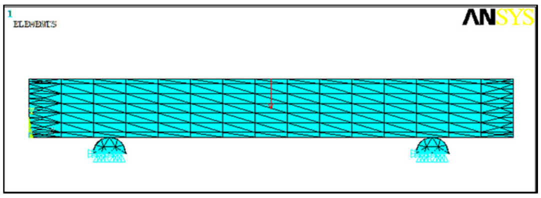

Figure 3 Meshed-bending sample.

The Poisson's ratio and elastic modulus of FG cores are define at a verity weight fractions of wollastonite from experiments (tensile test) are given as input to FEA as shown in table (4).

Table 4: Mechanical properties of sandwich layers.

υ	E (MPa)	Thickness (mm)	Volume Fraction	Concentration wt %	Layers
0.2	70000	1.5	0.5	-	Epoxy\ Carbon(textile)
0.3	35000	1.5	0.5	-	Epoxy\ Carbon (chopped)
0.41	14	3	-	0	1
0.4	20	3	-	1	2
0.4	25	3	-	2	3
0.4	30	3	-	4	4
0.4	36	3	-	8	5

The results obtained from the ANSYS program are as shown in figure (4), where similar loads are applied to the loads applied in practice and then compared to the resulting deflection with practical deflection.

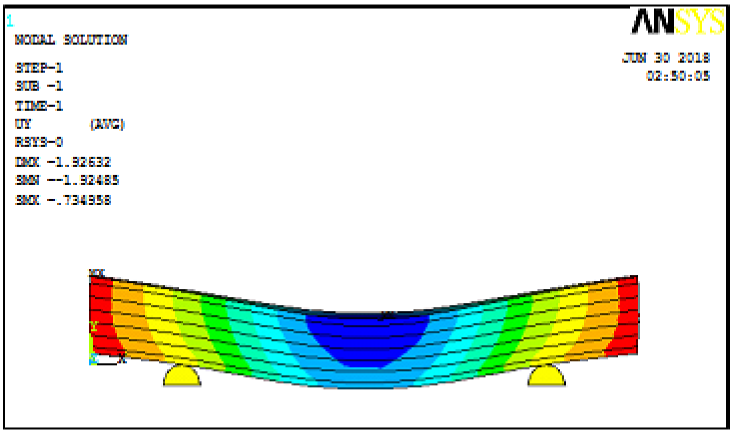

Figure 4 Results obtained from numerical simulation

3. RESULTS AND DISCUSSION

3.1. Bending test

The three-point bending conduct of a FG sandwich structure is explored beneath bending conditions. Load-deflection information is followed up and down the way.

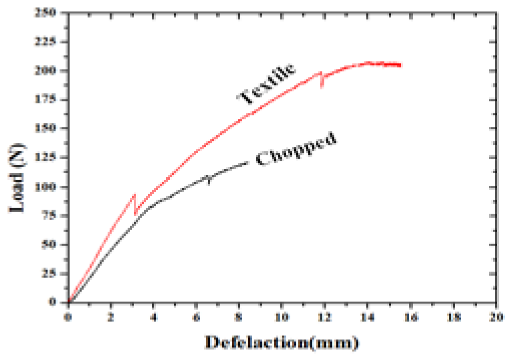

Figure 5 Three point bending behaviour of sandwich structure

The load and relating deflection information is mentioned at same period with interims up to a most extreme load at which the sample hints at the principal fail. The load and deflections got amid testing are plotted. A representative load-deflection graph is appeared in Figure (5).

Load-deflection comprises of an underlying straight portion taken before by a nonlinear segment. A nonlinear of materials examination that records of the consolidated impact of the nonlinear conduct of the skins and core materials (nonlinearity of material) and the substantial deflection of the beam (nonlinearity due to geometry) are watched. The nonlinearity of material of the sandwich bar is because of the nonlinear ordinary stress-strain conduct of the skin material and the FG core. For lengthy beam, despite the fact that there is a geometric nonlinearity impact.

For long beam traverses the nonlinearity of the load-deflection curvilinear is for the most part because of the joined impact of the facings nonlinearity and the extensive deflections of the bar. The two impacts, in any case, have a little participation to the load-deflection conduct, which demonstrates a little perversion from linearity.

The fracturing load taken from test is connected on finite element model to estimate the value of deflection and then compared to the resulting deflection with practical deflection.

It is important to take motion of that the test results for load deflection coordinate closely with FEA esteems as appeared in figure (6). It is watched that deflection got from FEA is somewhat lower than practice values. This could be because of failure of displaying inhomogenities creeping in amid the preparing of tests which may bring about bringing down quality of samples.

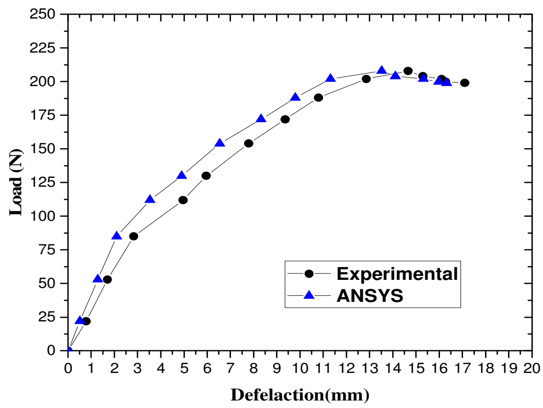

Figure 6 Load-deflection relation comparison for ANSYS and experimental bending test.

If want to compare the results of the theoretical and experimental results, will find that there is a good agreement, and also it is found that there is no more (10 %) discrepancy in the estimation of deflection, as shown in the Figure (6).This discrepancy in the estimated magnitudes of properties attributed to true loading condition, method of sandwich fabrication and so on [12].

3.2. Impact test

Experiments have been carried out to characterize the candidate sandwich composite beneath impacting load conditions, the analysis of the results and the effects of type of reinforcement on the impact strength are summarized in the figure (7).

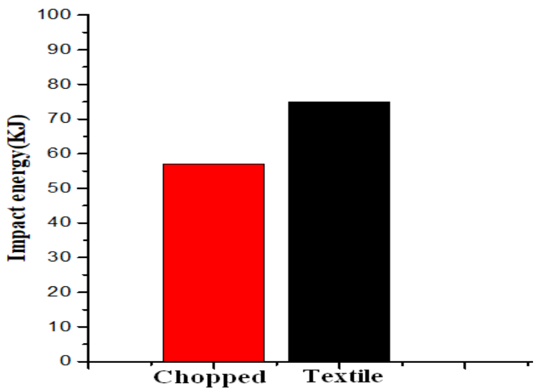

Figure 7 impact energy of two types of sandwich structure

From the figure it can be noted that the energy and therefore impact strength for sandwich which have unidirectional carbon reinforced composite skin are higher than chopped carbon reinforced, and this is due to woven of carbon which works to absorb more energy due to the nature of fabric in two directions, leading to the increased resistance of material to crack propagation which block the transmission of the crack through the material[13].

4. CONCLUSIONS

An experimental and numerical (by using ANSYS) study were done for particulate filled functionally graded rubber sandwiches to examine the impact of wollastonite weight fraction as a core in the sandwich composite as well as epoxy resin reinforced with carbon fibres serves as a skin in the sandwich structure.

The maximum torque for rubber filled with wollastonite increased with increasing wollastonite loading and Modulus significantly increased with increasing wollastonite loading.

The behaviour of a functionally graded sandwich composite is examined under bending loading condition, there is an acceptable agreement between experimental and theoretical results, where the discrepancy in the estimation of deflection less than (10 %).

The impact strength for the sandwich which has unidirectional carbon reinforced composite skin is higher than carbon reinforced with chopped fibres.

REFERENCES

[1] R. Mb And N. Integrated, “Flexural Behaviour Of Sandwich Composite Panels Fabricated Through Different Vacuum Bagging Techniques,” No. October, 2015.

[2] R. M. Mahamood, E. T. A. Member, M. Shukla, And S. Pityana, “Functionally Graded Material : An Overview,” Vol. Iii, Pp. 2–6, 2012.

[3] E. Bafekrpour, G. P. Simon, C. Yang, J. Habsuda, And B. L. Fox, “Fabrication , Characterization And Modeling Of Functionally Graded Synthetic Graphite / Polymer Nanocomposites Complimentary Contributor Copy,” 2013.

[4] C. Republic and C. Republic, “An Evaluation of the Stress Intensity Factor in Functionally Graded Materials,” Vol. 3, Pp. 401–410, 2009.

[5] S. Natarajan And M. Ganapathi, “Bending And Vibration Of Functionally Graded Material Sandwich Plates Using An Accurate Theory 1.”

[6] V. Birman And N. VO, “Wrinkling In Sandwich Structures With A Functionally Graded Core,” J. Appl. Mech., Vol. 84, No. 2, P. 21002, 2016.

[7] M. S. Kirugulige, R. Kitey, and H. V Tippur, “Science and Dynamic Fracture Behavior of Model Sandwich Structures with Functionally Graded Core : A Feasibility Study,” Vol. 65, Pp. 1052–1068, 2005.

[8] M. Doddamani and S. Kulkarni, “Sandwich Beams With A Graded Rubber Core under Flexural Loading,” Pp. 1–3.

[9] V. Birman, “Wrinkling In Sandwich Structures With A Functionally Graded Core,” Vol. 84, No. February, 2017.

[10] S. Mohammadi and F. Abdi, “Production Method of Rubber and Sulfur Fg Composites,” Pp. 63–69, 2012.

[11] A. International, “Standard Test Method For Rubber Property — Vulcanization Using Rotorless Cure,” Current, Vol. 9, No. Reapproved, Pp. 1–6, 1995.

[12] A. Ehsan, “Effect of Sulfur and Nano- Carbon Black on the Mechanical Properties of Hard Rubber,” No. 2, 2018.

[13] A. F. Hamzah, “Numerical Investigation of Drop Weight Impact on Peek Base Laminated Composite,” Iraqi J. Mech. Mater. Eng., Pp. 229–245, 2016.