Solidworks Simulation of Mechanical Properties of Recycled Plastics/Nanocomposite Faces Sandwich Panels

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Abstract– **Sandwich panels are lightweight, high strength materials desired by engineers for various applications. However, many contributions cited the replacement of the metallic surfaces with reinforced polymeric composites for additional weight reduction purpose but none observed for recycled plastics. Accordingly, this work plans to investigate the mechanical behavior of sandwich panels made of recycled plastic/Nano reinforced composites under tension, compression, and bending load using Solidworks simulation. The data were obtained from previous works, and the complementary data were collected using different approaches. All models revealed that polycarbonate (PC) skin dominated over polypropylene and high-density polyethylene due to the highest modulus of elasticity. However, the results indicated that the core unless reinforced the outer skins will be separated as a result of residual strain at interfaces. Consequently, the core of PC skin sandwich panel reinforced with two thin sheets which lead to improvement in loading endurance from 500 to 1500N without exceeding the allowable limits of the materials and leading to the birth of environmentally intimated material termed green sandwich panel.**

Index Terms–**Recycled plastic skins, reinforced core, sandwich panels, solidworks.**

I. Introduction

Sandwich panels are constructions of composite materials that provide engineers with desired properties as high mechanical performance accompanied by low weight. Sandwich panels consist of layers in which the outer thin metallic, polymeric, or fiber reinforced polymeric (GFRP) composites shields provide the desired mechanical properties as tensile strength, stiffness, and compression strength (Ramakrishnan, et al., 2015). The inner core of the panels consists of lightweight but mechanically weak materials such as rigid polyurethane foam which is usually used to enhance the bulk properties of the panels. However, the cons of the core can be excluded off by combining it in between two skins of higher mechanical features (De Almeida, 2009). On the other hand, replacement of metallic skins with other materials that offer lightweight and high strength properties with low cost is a novel goal for researchers. For instance (Azmi, et al., 2017), used glassed fiber composites to shield the polyurethane foam core sandwich. The core itself reinforced additionally with coconut coir fibers to optimize the mechanical and physical properties of the sandwich panels. Bending test showed that modulus of the flexural ratio of sandwich composites to the naked core was 3084%. Furthermore, the probability of replacing reinforced concrete in the bridge deck with glass reinforced polymers foam core composites has been studied by Tuwair, et al., 2015. Three types of composites were investigated. Type1 high-density polyurethane (HDPE) foam and Type 2 low- density polyurethane foam reinforced with two-dimensional GFRP network, whereas Type 3 was trapezoidal-shaped polyurethane foam armored with extra GFRP web. The mechanical tests showed that Type 3 outperformed both Type 1 and Type 2 due to the weakness and the softness of the first two inner core types.

In addition (Kumar and Soragaona, 2014), optimized the design parameter of multilayer sandwich panels by optimizing the ratio of the outer sheets thickness to the overall thickness of the sandwich panels. The specimens were fabricated in a different manner that they consisted of multilayer sandwich panels', that is, face- core- face- core- face in which two thicknesses of the faces (1 mm and 2 mm) were examined and compared to face-core-face composites. The practical works showed that multilayer composites stiffness was superior to the normal design.

Utilizing the recycled plastics in sandwich panels unlike the virgin polymeric composites is still a fertile land for investigations. Moreover, knowing the disastrous effects of the plastic wastes on the environment will motivate us toward exploiting them as second-hand materials instead of tossing them in landfills. It is well known that the accumulation of polymeric wastes damages the ecological system. Take burning pit as an example, In Iraq, US military had burned

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147 tons of waste per day in 2008 and abundant pollutants emitted into the air as combustion results causing long-term hygienic impacts. The most dangerous pollutant was highly toxic dioxins related to burning of plastic waste as rejected water bottles (Azeez, 2017). Accordingly, this research work for the 1st time reports on modeling sandwich panels from rubbish plastic/nanoparticles composites outer skins. The power of finite elements will be utilized to characterize the digital samples of sandwich panels using Solidworks software. The samples will be investigated under different work conditions based on technical data cited from previous literature.

II. Methodology

A. Technical Data of the Materials

The studied sandwich panel in this study consists of recycled plastic/nanofiller composite outer skins and polyurethane foam in between. The technical data from previous works have been taken into consideration in order to implement Solidworks. Hence, the materials that are candidate to replace the metallic surfaces of ordinary sandwich panels due to their superiority as observed in the literatures are recycled polypropylene (PP)/3% carbon nanotubes (CNT) composite (Liu and Gao, 2011) symbolized as PPC, recycled HDPE/4% nano graphene composite (Reddy, 2006) termed (HDPEC), and recycled polycarbonate (PC)/3% CNT composite (Zhang, et al., 2017) abbreviated as PCC. Accordingly, yield strength, ultimate strength, and modulus of elasticity were directly extracted from aforementioned works. Unfortunately, not all data were found in the articles, so they had to be collected through different scenarios. For instance, tensile test overwhelmed the mechanical characterization of the materials, and no record was found for compressive strength. To estimate the compression property required for Solidworks, the same trend will be followed as in the tensile test. For example, the tensile strength of virgin PP is 34.1 MPa and after one run of recycling the strength degraded by 2% to 33.39 MPa (Mahendrasinh, et al., 2013). By the addition of only 3% of CNT, the strength of the recycled PP increased by 71.75% (Liu and Gao, 2011). Now, assuming that the PP behavior is similar in compression and tension, one can approximately estimate the compressive strength of PPC by following the same fluctuating in its property. Therefore, if the compressive strength of pristine PP is 55 MPa (eFunda Polymers, n.d.) then after one batch of recycling it will reduce about 2% to 53.9 MPa which will, in turn, shift up about 71.75% to 94.46 MPa by considering the improvement effect of 3% CNT addition. Following the same procedure, the compressive strength of HDPEC and PCC estimated to be 33.44 and 56.1 MPa, respectively. However, the effect of recycling and improvement and the virgin values of compression strength of HDPEC and PCC with their sources can be found in the Appendix I. On the other hand, no contribution found regarding the effect of recycling and improvement on the Poisson's ratio and the effect on density could be worthless. Consequently, the simple rule of the mixture was used to find the Poisson's ratios and the densities (Appendix II). Finally, the technical data used to run Solidworks are listed in Table I.

III. Modeling and Simulation

A. Flatwise Compression Test

The specimen of the sandwich panel for the compressive wise test is modeled according to ASTM C 365/C 365M–05 with dimensions 20 × 25 × 25 mm. The faces thicknesses were taken as 2 mm each. Load of 500N applied on the top surface while the bottom constrained. The key scope of this test is to characterize the load capacity of the structure under compression condition (ASTM, 2005).

B. Flatwise Tensile Test

The main goal of flatwise tensile is to determine the bonding integrity between the core and the faces. The samples were designed following ASTM C297/C297M-04 standards with same dimensions and load condition of flatwise compression test (ASTM, 2004).

C. Bending Test

Sandwich panels are widely used as roofing in construction materials; hence, they are vulnerable to bending due to their load condition. As a result, the flexural test is conducted in our study to optimize the performance of the structure based on the outer skin mechanical endurance. Samples with dimensions of 560 × 25 × 20 mm were designed according to ASTM 7249/7249M-12 and subjected to the distributed load of resultant 500N, and the gravity was also considered. The thicknesses of the outer surfaces were 2 mm each as in the previous tests (ASTM, 2012).

IV. Results and Discussion

A. Flatwise Compressive Simulation

The results of finite element analysis of flatwise compression properties of sandwich panels are shown in Fig. 1. PCC faces sandwich panels overwhelmed the others mechanically due to highest stress endurance (4274KPa) compared to 2824 and 2946 KPa for PPC and HDPEC skins, respectively. However, the highest stress value in PCC was accompanied with least deformation of about 0.85 mm compared to more than 0.9 mm for the other faces indicating the rigidity of PC skin.

TABLE I
Technical Data of Materials

Properties of Materials	PPC	HDPEC	PCC	Polyurethane foam
Elastic modulus (MPa)	243	507.913	6000	13.61[a]
Poisson's ratio	0.417	0.45	0.418	0.33[b]
Shear modulus (MPa)	85.7	175	2115.65	5.11
Mass density Kg/m^3	917	973	1386.8	32[a]
Tensile strength (MPa)	39.69	12.4	54	0.485[a]
Compression strength (MPa)	94.46	33.865	65	0.287[a]
Yield strength (MPa)	39.69	11	54	0.265[a]

[a]Sparks and Arvidso, 1984, [b]Dai, et al., 2015

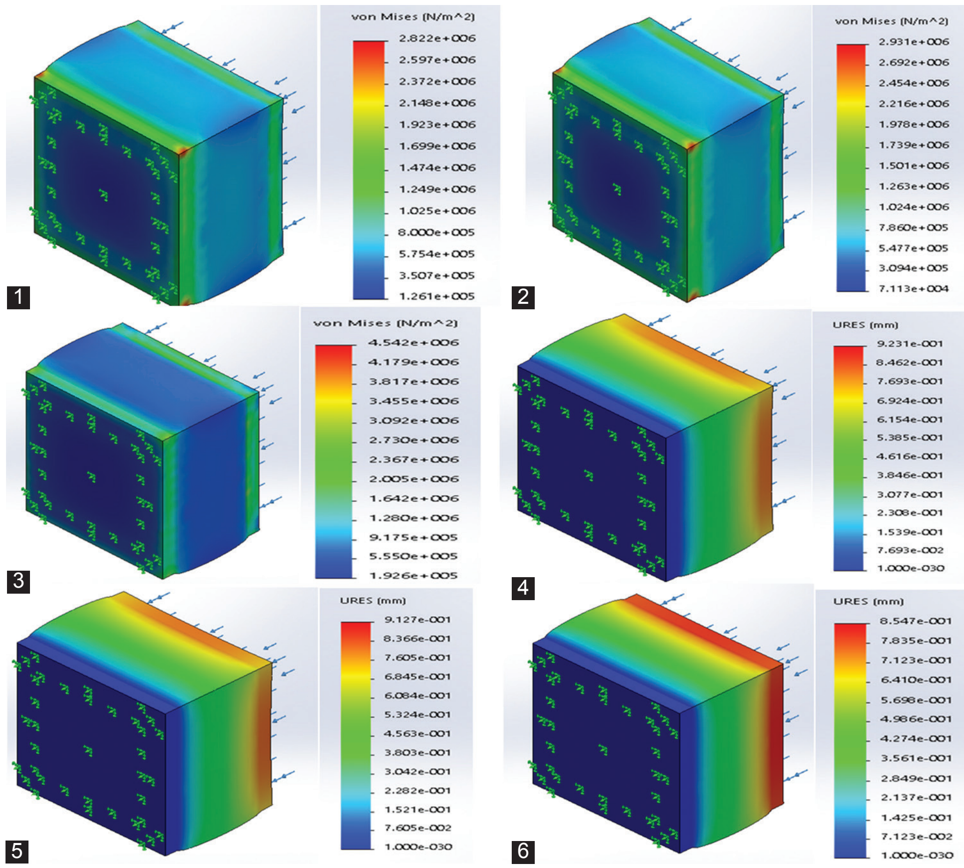

Fig. 1. (1-3) Von Mises stress, (4-6) displacement results for PPC, HDPEC, and PCC.

Since the Solidworks models simulated elastically, the previous behaviors can be explained according to the modulus of elasticity, which is at highest value in recycled PC as listed in Table I.

On the other hand, despite that lower displacement leads to lower strain, an inverse trend observed in PCC at shield/core interfaces where the strain was highest as shown in Table II. This problem will be discussed briefly in the next section.

B. Flatwise Tensile Simulation

Results of the flatwise tensile test were comparative to compression test listed in Table II with negligible difference in the values. The spectrums of the strain throughout the thickness indicate the main concern to be considered otherwise splitting of the faces from core occurs that are the residual strain at the interfaces colored in red as shown in Fig. 2 The main cause of such strain concentration is the divergence of the materials properties at a specific point instead of gradual variation (Attiyah and Azeez, 2014).

To support this physical point of view, we may calculate the ratios of Hock modulus differences between the surface and core. The modulus fraction of the PCC to polyurethane foam determined to be 99.77% compared to 97.3% and 94.3% for HDPEC and PPC, respectively.

Accordingly, the strain concentration in PCC sandwich panels exceeded the others as stated in Table II due to sharp differences in the modulus of elasticity. On the other hand,

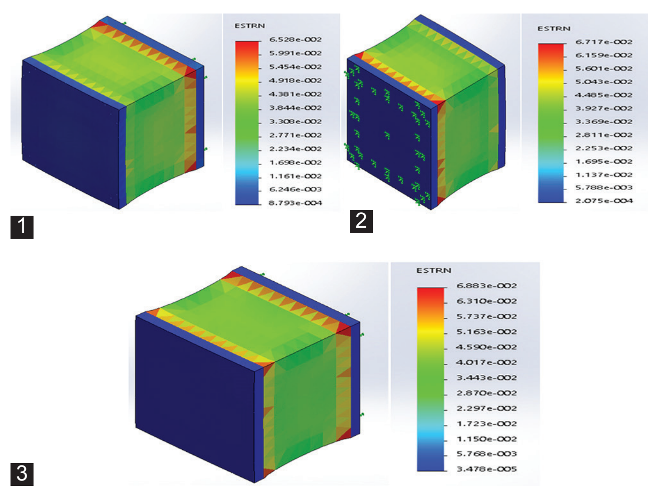

Fig. 2. Residual strain at interfaces in (1) PPC, (2) HDPEC, and (3) PCC.

TABLE II
The Results of Flatwise Compression Test

Sandwich panels	Von Mises stress (KPa)	Strain (mm/mm)	Deformation (mm)
PPC	2822	6.534E-2	0.9231
HDPEC	2931	6.714E-2	0.9127
PCC	4542	6.888E-2	0.8547

the yield strain of polyurethane foam as reported by Sparks and Arvidso, 1984, is about 3% whereas the strain in all

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models exceeded the double which will lead to peeling the skin from the core unless the foam reinforced.

The best model which is PCC skin was redesigned and the foam armored with a 1.5 mm strips with the same material of the skin. This modification not only protected the core but also leads to triple improvement in the bearing capacity from 500N to 1500N without exceeding the maxima of the materials Fig. 3. The maximum stress was 39.42 Mpa with only 0.2739mm deformation and 3% strain at the interface.

TABLE III
Flexure Test Results

Sandwich panel	Von Mises stress (MPa)	Strain (mm/mm)	Deflection (mm)
PPC	6.631	2.267E-2	21.7
HDPEC	7.869	1.844E-2	16.15
PCC	13.43	1.368E-2	4.248

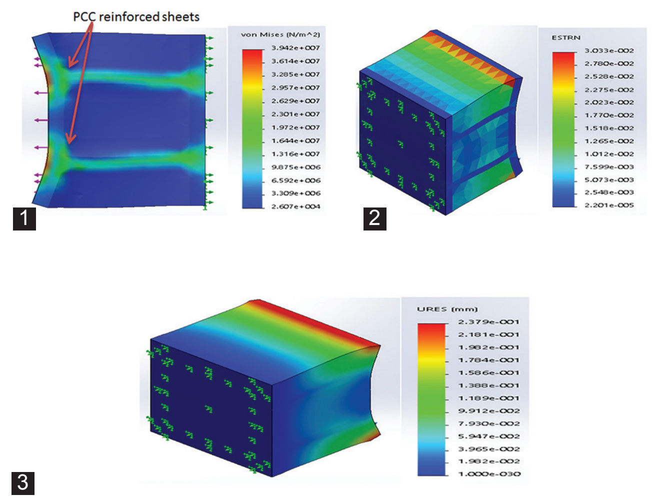

Fig. 3. (1) Von Mises stress, (2) strain, and (3) displacement in reinforced core in PCC sandwich panel.

C. Bending Simulation

The resistance of the construction materials to deflection is a top concern for civil engineers since the majority of the loading condition in buildings, and specifically, the roofing is bending.

However, Solidworks modeling in flexure also emphasized the superiority of recycled PCC over the other. The distribution of Von Mises stress, strain, and the deflection within the structure is listed in Table III.

Again PCC endured the highest stress with a minimum deflection in midpoint as this is clear in Fig. 4. In addition to that, fortunately, all results were within the allowable limits provided by Table I.

V. Conclusions

All models revealed that PCC dominates over PPC and HDPEC due to high stiffness. However, the core should be reinforced to prevent separation at interfaces because of strain concentration. This is proposed to support the foam with two thin sheets of PCC. The subsequent modification in the design leads to spectacular results. The loading capacity multiplied 3 times, and the resulted values never exceeded

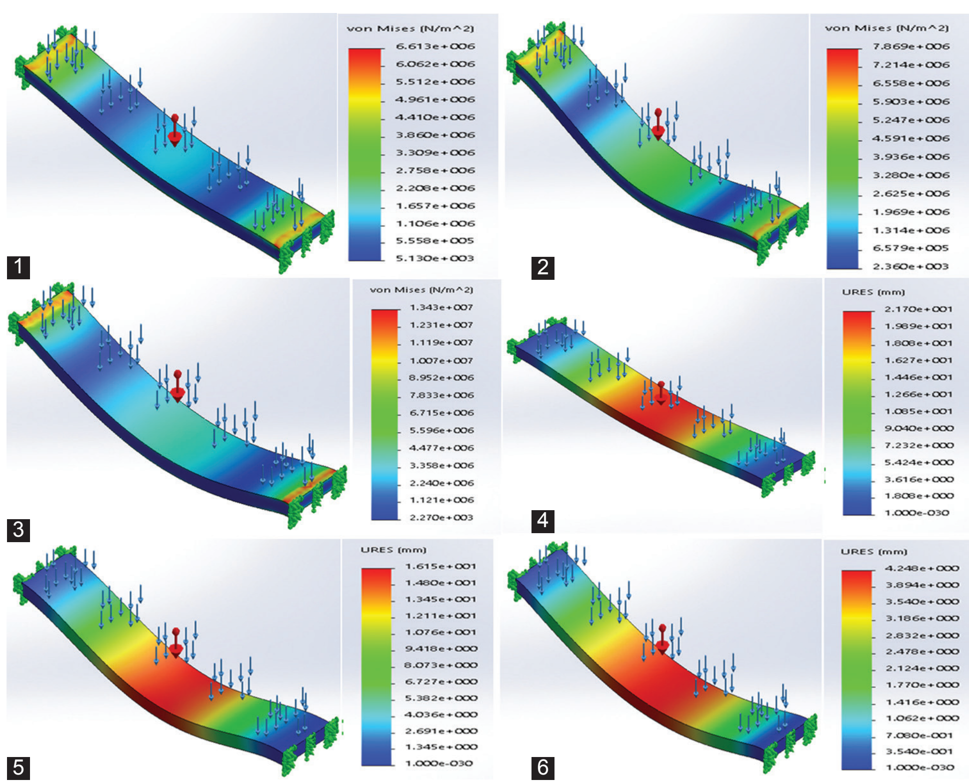

Fig. 4. (1-3) Von Mises stress, (4-6) deflections for PPC, HDPEC, and PCC respectively.

VI. Appendices

APPENDIX A

The Effect of Recycling and Nano Improvement on the Mechanical Properties of the Materials

Materials	Virgin Properties	Effect of recycling	Effect of filler on recycled properties	Sources
HDPE behavior in tensile		16.6% degradation[a]	63.3% increase[b]	(Jiun, et al., 2016) (Reddy, 2006)
HPEC compression strength (MPa)	24.82[c]	20.7	33.865	(Corneliussen, 2002)
PC behavior in tensile		2% increase[d]	Not significant[e]	(Ronkay, 2013) (Zhang, et al., 2017)
PCC compression strength (MPa)	55[f]	56.1	56.1	(Kingston, et al., 2014)

APPENDIX B

Densities and Poissons' Ratio of the Materials

Types of materials	Density Kg/m^3	Poisson's ratio	Sources
PP	908	0.42	Typical engineering properties of PP, (2014)
HDPE	965	0.45	Typical engineering properties of HDPE, (2014)
Poly carbonate	1380	0.42	AZO materials
Nanotube and grapheme	1400[a]	0.3[b]	(Kumar, et al., 2018) (Zhao and Shi, 2011)

the allowable limits of the materials. On the other hand, shielding the panels with recycled polymeric strengthened composites leads to a new concept which may be termed as green sandwich panels.

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