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Influence of the Ratio on the Mechanical Properties of Epoxy Resin Composite with Diapers Waste as Fillers for Partition Panel Application

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Abstract:
Materials play significant role in the domestic economy and defense with the fast growth of science and technology field. New materials are the core of fresh technologies and the three pillars of modern science and technology are materials science, power technology and data science. The prior properties of the partition panel by using recycled diapers waste depend on the origin of waste deposits and its chemical constituents. This study presents the influence of the ratio on the mechanical properties of polymer in diapers waste reinforced with binder matrix for partition panel application. The aim of this study was to investigate the influence of different ratio of diapers waste polymer reinforced epoxy-matrix with regards to mechanical properties and morphology analysis. The polymer includes polypropylene, polystyrene, polyethylene and superabsorbent polymer (SAP) were used as reinforcing material. The tensile and bending resistance for ratio of 0.4 diapers waste polymers indicated the optimum ratio for fabricating the partition panel. Samples with 0.4 ratios of diapers waste polymers have highest stiffness of elasticity reading with 76.06 MPa. A correlation between the micro structural analysis using scanning electron microscope (SEM) and the mechanical properties of the material has been discussed.

***Keywords:** Polymers, Diapers waste, partition panel, mechanical strength.*

I. INTRODUCTION

Partition panel is an interior wall that has been installed in a building development as a non-load bearing wall. In essence, partition panel is a thin wall component designed to split the indoor room into chambers or other compartments. The primary structural requirement of a partition panel is to have the required power to promote appropriate resistance to accidental effects caused by the occupants of the building [1]. Partition panels were launched from the late 15th century, known as Wall Paneling, and a fresh national structure began to develop at the start of the 16th century. Since the 1960s, prefabricated office wall partition systems that stimulated stick constructed walls have been accessible [2]. Sustainable and environmentally accountable material specification in building design has risen in latest years owing to concerns about decreasing the embodied energy of products and increasing possibilities for recycling and promoting biodegradability at the end of a building's life [3]. Therefore, there have lately been a numerous of study within the scientific community that have tested and analyzed polymer performance within multiple binder matrices to determine flexural, tension and compression strength features as well as durability performance.

Today's diapers are high performance and well-tested products intended to maintain the skin dry and healthy. They are mainly produced of biologically inert polymers, widely used in skin contacting fabrics and other products, as well as in food and cosmetics. Diapers are absorbent or known as personal hygiene incontinence goods intended to absorb and maintain urine and feces from children or adults with incontinence problems. An average diaper of 1.4 and 1.8 ounces weighed mainly cellulose, polypropylene and polyethylene along with a super absorbent polymer, as well as tapes, elastics and adhesive materials [4]. Average weight for clean diapers is 41g while 212g for used diapers [5]. Cellulose pulp contains 35% in diaper composition is a form of pulp, a product produced from a mixture of wood chips and chemical products where lignin, the protein that binds cellulose fibers together, breaks down [6]. Superabsorbent polymers (SAP) are found to be 33% of the weight proportion and used to absorb, soluble and maintain liquid in diapers comprises of a polymer of repeating sodium polyacrylate monomers (C3H3NaO2). Polypropylene nonwoven has two components in diapers that are hydrophobic and hydrophilic [7]. Hydrophobic polypropylene nonwovens are impermeable to liquids and are used in the cross area as leak guards. This feature is intended to prevent leaks in the leg cuff's diaper region. The fluid-permeable top layer in contact with the baby's skin is hydrophilic polypropylene nonwovens.

II. EXPERIMENTAL PROCEDURE

Materials

To obtain the new composite materials based on diapers waste, recycled polypropylene, polystyrene, polyethylene and superabsorbent polymer (SAP) were used as reinforcing material as shown in Figure 1. To determine the particle size of the polymers, the polymers were ground using high speed grinder with 30mesh blade which particle size range from 0.500mm to 0.595mm. The diapers wastes are obtained from the industrial process which free from any contaminations. The epoxy resin as binder was used to achieve adhesion with the reinforcing materials. The commercial binder used in this study was Epoxy Resin DER 324 produced by DOW Company and Jointmine 905-3S.D.E.R. 324 the liquid epoxy resin is smaller than the other modified liquid epoxy resins with a surface tension (≈ 15 percent). The reduced surface tension results in excellent surface weathering, adhesion and reduced viscosity when filled with filler. The relatively low viscosity combined with the slightly fewer surface pressures will save the formed system as more filler can be added to obtain the same viscosity. The selected properties of the resin and hardener are shown in Tables 1 and Table 2, respectively. The mix ratio for both resin and hardener reported in the technical data sheet is 3:1 by weight of epoxy resin to hardener as shown in Figure 2.

Figure 1 : Ground Diapers Waste

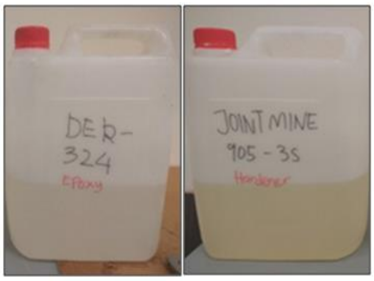

Figure 2: Commercial Binder; (A) DER 324 Epoxy Resin, (B) Joint mine 905-3S Hardener

Table 1: Selected parameters characterizing DER 324 epoxy resin

Resin Type	Epoxide Equivalent Weight (g/eq)	Epoxide Percentage (%)	Viscosity (mPa.s)	Density (g/ml)	Shelf Life (Months)
DER 324	195-204	21.1-22.1	600-800	1.1	24

Table 2: Selected parameters characterizing Jointmine 905-3S hardener

Hardener Type	Chemical Name	Viscosity (poise)	Pot Life (100g @ 25C)	Amine Value (mgKOH/g)	Density (g/cm3)	Color
Jointmine 905-3S	Modified polyamine	200-400	75 min	320±20	1.13-1.90	Amber color

March - April 2020
ISSN: 0193-4120 Page No. 10141 - 10151

Sample Preparations

The following steps were performed to acquire the epoxy composite materials. The polymer components of diapers waste (DW) were ground using high speed grinder machine with speed 3450rpm and weighted based on the set of ratio as shown in Table 3. The epoxy resin was mixed with the hardener at 3:1wt ratio and manually stirred for 5minutes. The weight ratio of epoxy resin and hardener remain constant while the weight of the DW difference to determine the optimum ratio of DW in the fabricating partition panel. Then, the mixture of epoxy matrix were mixed thoroughly with the DW and poured into prepared mould. Hand layup method was used for pouring into the prepared mould. The mixture were left for curing process for 24hours in room temperature (24±2ºC) for the completion of the chemical reaction as shown in Figure 3. Figure 4 shows the sample after curing process.

Table 3: Ratio of DW for sample preparation

Samples	Ratio of DW	Ratio of DER 324 epoxy resin	Ratio of Jointmine 905-3S hardener
A	0.0 (Control Sample)	3	1
B	0.1	3	1
C	0.2	3	1
D	0.3	3	1
E	0.4	3	1
F	0.5	3	1
G	0.6	3	1

Figure 3: Epoxy resin composite poured into prepared mould

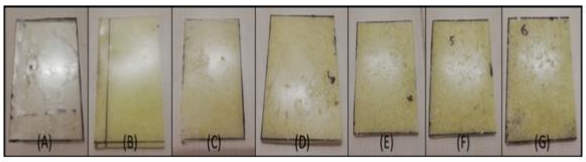

Figure 4: Sample after curing process

III. METHODS

Tensile Strength Test

Tensile strength test was conducted accordance to the ASTM D3039/D3039M-17, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. The test was carried out by using Universal Testing Machine (VEW 2308D Computer Servo Type) as shown in Figure 5. The typical test speed for standard test specimens was 2mm per minute or 0.05 inches per minute. The composite materials were cut by using Sawyer Circular Bend Saw (Model No.: HB600A) with 25mm width and 250mm length. The specimen was placed in the grip of the tensile testing machine and test performed by applying tension until it undergoes fractured. Three tests per specimen were conducted, then the average value obtained recorded for data analysis

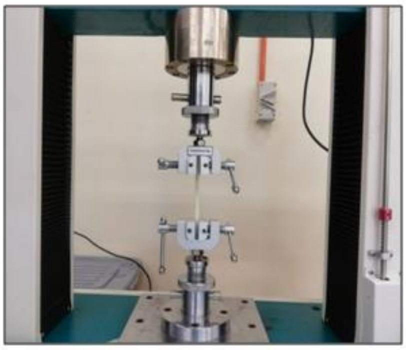

Figure 5: Universal Testing Machine for Tensile Strength Test

Flexural Strength Test

Flexural strength used to assess the material's ability to tolerate load deformation. The bending properties like strength, rigidity, loading or deflective behavior must also be calculated. Statistics derived from this study include flexurity, average pressure, pressure tension and overall flexurity.Flexural strength test was measured according to the ASTM D7264/D7264M-15, Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials by using Universal Testing Machine (VEW 2308D Computer Servo Type) as shown in Figure 5. Three point loading system for center loading types of flexural strength were shown in schematic diagram in Figure 6.Force are exerted at the centre of the specimen with two supporting structure at both endThe specimen were prepared with 4mm thickness, 13mm width and 150mm length. Three specimens were tested per sample and the average value taken for data analysis.

March - April 2020
ISSN: 0193-4120 Page No. 10141 - 10151

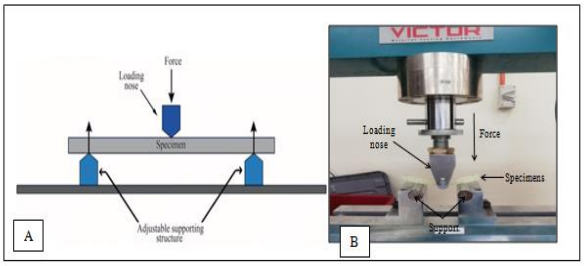

Figure 6: Flexural Strength Test; (A) Schematic diagram of 3 point loading test; (B) Universal Testing Machine

Izod Impact Strength Test

Impact strength test is used to determine the sample brittleness after impact in standard stress conditions and to measure energy consumption before fracturing under high deformation. Izod impact strength test were conducted accordance to ASTM-D7136/D7136M-15, Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event. The testing was carried out by using INSTRON CEAST 9050 Pendulum Impact System (Motorized Model) and as shown in Figure 7. The machine has a pneumatically operated hammer release and braking system as per standard. Specimens were prepared with 3mm thickness, 13mm width and 150mm length, then the samples were notched using automatic Instron CEAST AN50 notching machine with appropriate knife to make V notch (45° angle, radii 0.25 and 1 mm) as shown in Figure 8 (B). Three specimens were prepared for each ratio of the DW epoxy composites and the average values were recorded for data analysis.

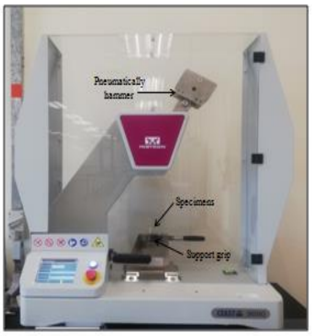

Figure 7: CEAST 9050 Motorized Pendulum Impact Systems

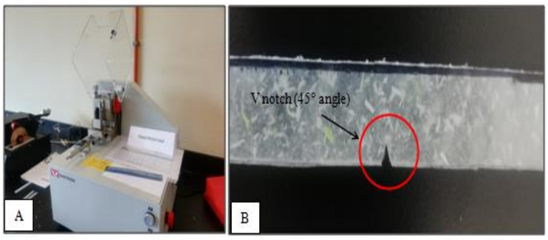

Figure 8: Notching process; (A) CEAST Specimen Preparation Notching Machines; (B) Sample after

Compressive Strength Test

Compressive Strength was conducted based on ASTM D695, The Standard for Compression Strength and Modulus of Plastic Materials Used in Various Engineering Applications. The test was carried out using Universal Testing Machine (VEW 2308D Computer Servo Type). Compression test is a necessary testing method for all materials that used to establish the compressive force or crush resistance of material and the ability of the material to recover after a specified compressive force are applied. Compression test is to measure the material behavior under a load. The speed of the compression test was 0l.05 inches per minute or 1.27 mm per minute. The specimens were prepared in cylindrical shape with 25 mm diameters and 50 mm length. The samples were placed perpendicular to the plate of the testing machine and centrally on the base plate of the machine as shown in Figure 9. The maximum load and compressive strength were recorded after the sample failed.

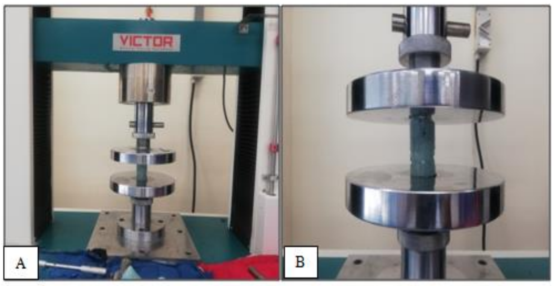

Figure 9: Compressive strength test; (A) Universal Testing Machine; (B) Sample placed under compression load

Scanning Electron Microscope (SEM)

SEM analysis were conducted by using analytical Scanning Electron Microscope (SEM), model no: JEOL JSM-6380LA MP-19500014 with standard accordance to ASTM E766-14e1, Standard Practice for Calibrating the Magnification of a Scanning Electron Microscope with an acceleration voltage of 15kV. The SEM analysis uses broken tensile strength test specimen to evaluate the

March - April 2020
ISSN: 0193-4120 Page No. 10141 - 10151

image of the cross section for the damaged sample with various compositions of DW. The chosen specimens were cut into smaller size around 15mm long and 25mm wide. Prior to the scanning, the samples were coated with a thin layer of gold as shown in Figure 10.

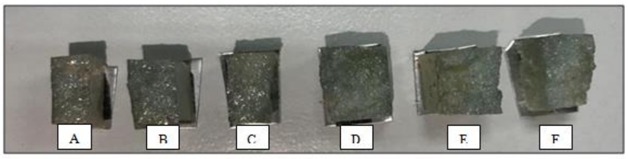

Figure 10: Cross-section of fractured specimens with different ratio of DW; (A) Ratio of 0.1 DW, (B) Ratio of 0.2 DW, (C) Ratio of 0.3 DW, (D) Ratio of 0.4 DW, (E) Ratio of 0.5 DW, (F) Ratio of 0.6 DW

IV. RESULTS AND DISCUSSION

Tensile Strength Test

Figure 11 presents the comparative tensile strength and young modulus of DW/epoxy composites under tensile strength test. It is obvious that the tensile properties of the DW/epoxy composites with higher ratio achieved higher values than the control sample of the pure epoxy matrix. The maximum tensile strength value was obtained for the composites containing ratio of 0.4 DW than the control sample of pure epoxy matrix. The tensile strength of the ratio of 0.4 DW/epoxy composites recorded an augmentation from 1.12MPa to 6.11 MPa, while the young modulus were contrast from the tensile strength which is the ratio of 0.1 and 0.2 of DW were lowered than control sample of pure epoxy resin. Samples with 0.4 ratio of DW have highest stiffness of elasticity reading with 76.06 MPa. The Young Modulus increased up to ratio of 0.4 DW however, reducing for more than ratio of 0.4 DW due to the effect of polymer arrangement and viscosity of the resins [8].

The higher tensile strength of the sample is because of the lower viscosity of the epoxy resins interfacing between the DW are better than others [9]. The SEM micrograph showed very good dispersion of the DW fillers in the epoxy and may be the reason for good tensile strength. The fractured sample shows that ratio of 0.1 and 0.2 of DW/epoxy composites were stretched after testing was done (Figure 12). This shows that the brittleness of both ratioswas lowered compared to others. The brittleness of the sample was main factors to determine the strength of the samples. According to the materials' morphological assessment, the increase in the DW ratio results in a well-defined cell structure that provides a greater mechanical strength compared to a lower diapers waste ratio. The interface plays a significant role in composite materials ' mechanical properties. The interface load transfer from the matrix to the distributed phase [10]. The mechanical properties get worse as the filler loading increased beyond the certain level, as the composites became much brittle as ratio 0.5 and 0.6 of DW/epoxy resin composites (Basheer, 2019).

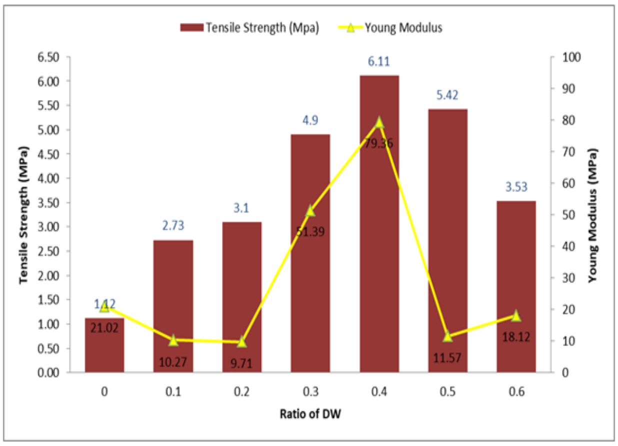

Figure 11: Tensile properties of DW/epoxy composites

Figure 12: Physical properties of the tensile strength sample after tested; (A) Control Sample, (B) Ratio of 0.1DW, (C) Ratio of 0.2 DW, (D) Ratio of 0.3 DW, (E) Ratio of 0.4 DW, (F) Ratio of 0.5 DW, (G) Ratio of 0.6 DW

Flexural Strength Test

Figure 13 presents the flexural strength for different ratio of DW reflected in bar graph for comparison. The graph trend increase up to ratio of 0.4 DW and slightly decrease from ratio of 0.5 DW. It apparently exhibited that the ratio of 0.4 DW withstand the highest flexural strength with 22.92 MPa, followed by 0.5 DW with 21.32 MPa, 0.6 DW with 20.83 MPa, then 0.3 DW with 14.34 MPa, 0.2 DW with 14.16 MPa and lastly ratio of 0.1 DW withstand with 12.90 MPa of flexural strength. The significant reinforcement caused by the incorporation of continuous and aligned diapers waste into the epoxy matrix [11].The physical properties of the failed samples after tested under flexural load.The failure of all the ratio

March - April 2020
ISSN: 0193-4120 Page No. 10141 - 10151

with DW under flexural loading shows the ductile mode respectively. The sample shows the deformation when force exerted. The curves revealed the MSWPC-DW reinforced epoxy composite shows the limited deformation with a rupture tendency just beyond the elastic limit.

The highest value of the failure for ductile mode shows that the control sample with 65.25mm deflection, followed by ratio of 0.4 DW with 34.82mm, ratio of 0.3 DW with 34.07mm, 0.6 DW with 32.54mm, then ratio of 0.1 DW with 32.34mm, 0.2 DW with 30.94mm and the lowest value of the deformation is 0.5 DW with 27.07mm. The brittleness of the sample were determined as the sample fractured at the lower value of deflection. Chemical composite treatment plays a very important role in enhancing interfacial adherence between DW and epoxy, further contributing to increased flexural strength [12]. Figure 14 shows the physical properties of the samples after flexural test were done.

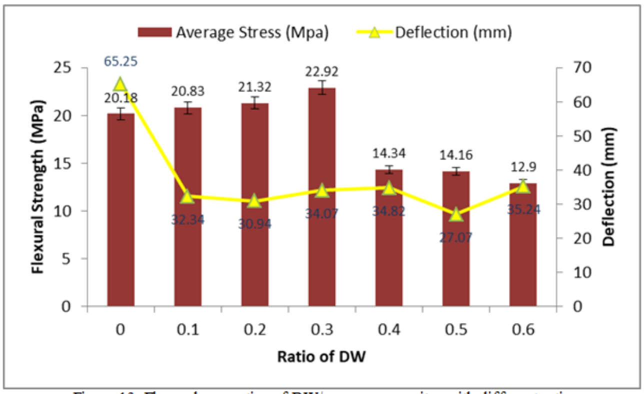

Figure 13: Flexural properties of DW/epoxy composites with different ratio

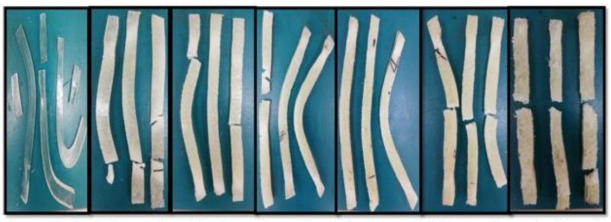

Figure 14: Physical properties of the flexural strength sample after tested; (A) Control Sample, (B) Ratio of 0.1 DW, (C) Ratio of 0.2 DW, (D) Ratio of 0.3 DW, (E) Ratio of 0.4 DW, (F) Ratio of 0.5 DW, (G) Ratio of 0.6 DW

Izod Impact Strength Test

Figure 15 illustrates the relationship between energy absorbed and impact strength for different ratio of DW. The highest impact strength achieved by ratio 0.4 of DW with 25.65 kJ/m2 followed by ratio 0.5 of DW with 10.36 kJ/m2, then ratio 0.6 of DW with 7.2 kJ/m2. Ratio 0.3 of DW obtained 6.88 kJ/m2 and then ratio 0.2 DW with 4.19 kJ/m2 , ratio 0.2 DW and control sample achieved same value of impact strength with the lowest value with 1.95 kJ/m2.

Epoxy-resin composites with filler of diapers waste exhibit insufficient resistance to fractures under impact loading [13]. The introduction of the DW as fillers in the epoxy resin composites does not weaken the properties of the materials and developed method of manufacturing of such materials. The strength of the polymer composites can be influenced by a number of factors, such as the essential properties of the matrix, the composite volume fraction, and interfacial bond strength [14]. The energy absorbed is continuously increasing with weight ratio of DW in epoxy resin till ratio 0.4 DW, and then suddenly falling to 0.81% energy absorbed at ratio 0.5 DW. It was clear that the presence of the DW impaired the impact energy absorbed of the composites. The polymer incorporation into the matrix significantly improves the impact toughness of the composite [15]. M.A. Barcelos et al (2014) stated that the behaviour of polyester matrix composites reinforces results in a visible improvement in energy absorption ability of the composites. The increase in fiber / matrix decohesion and the tensile fracture of the micro fibrils can be related to the exponential growth which results in higher absorbed energy due to the longitudinal distribution of cracks and the numerous areas broken off [16]. Composite impact performance is greatly influenced by the hardness of the DW, the interfacial adhesion and the friction work needed to pull-out the fiber from its matrix [17]. Figure 16 shows the physical properties of the samples after impact test.

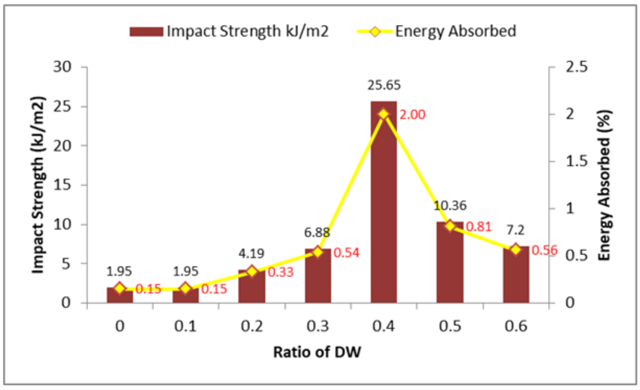

Figure 15: Impact properties of DW/epoxy composites for different ratio

March - April 2020
ISSN: 0193-4120 Page No. 10141 - 10151

Figure 16: Fractured sample of DW/epoxy with different ratio, (A) Ratio of 0.1 DW, (B) Ratio of 0.2 DW, (C) Ratio of 0.3 DW, (D) Ratio of 0.4 DW, (E) Ratio of 0.5 DW, (F) Ratio of 0.6 DW

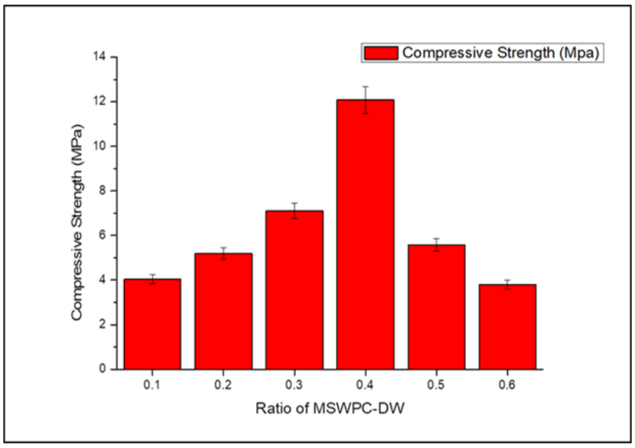

Figure 17: Compressive strength of the DW/epoxy composites with different ratio

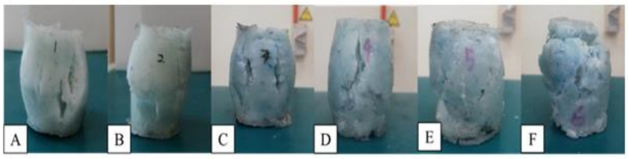

Figure 18: Physical properties of DW/epoxy composites after testing, (A) Ratio of 0.1 DW, (B) Ratio of 0.2 DW, (C) Ratio of 0.3 DW, (D) Ratio of 0.4 DW, (E) Ratio of 0.5 DW, (F) Ratio of 0.6 DW

Compressive Strength Test

To determine the effects of the DW as fillers on the mechanical properties of the cured epoxy resin, the compressive strength test were performed on the composites that contains different ratio of the DW particles. The sample shows the deformation after the force exerted as we can see in the Figure 18. All samples are back to its shape after tested under compression load. This is because the properties of the epoxy-matrix in this application were flexible. At the ratio of 0.6 DW, the samples are not flexible because the filler inside the reinforcement were too much. The interfacial bonding between the filler and epoxy matrix are very poor.

From the compressive properties of the matrix resins, it can be seen that the addition of the DW fillers increase the compressive strength of the DW/epoxy composite up till ratio of 0.4 DW and slightly decreased from the ratio of 0.5 to 0.6 DW. According to Figure 17, the highest value of the compressive strength was ratio of 0.4 DW with 12.09 MPa, followed by ratio of 0.3 DW with 7.11 MPa, then ratio of 0.5 DW with 5.59 MPa, ratio of 0.2 DW with 5.18 MPa, continued with ratio of 0.1 DW with 4.04 MPa and lastly the lowest value of compressive strength achieved by ratio of 0.6 DW with 3.81 MPa. There is a fluctuation of the compressive strength improvement with the increment of the ratio of DW could be due to the defect generated during the fabrication process of the DW/epoxy composites [18].From the testing results, it can be seen that the introduction of the DW fillers into the epoxy resins influenced the compressive strength property of the epoxies.

Scanning Electron Microscope (SEM) Analysis

Figure 19 displays the SEM images of fractured surfaces of the tensile strength sample of MSWPC-DW reinforced with epoxy matrix respectively. SEM clearly identifies the cross-section morphology and microstructure of the composites, indicating the factors determining the earlier rupture during the mechanical tests. Figure 19 (A) presents the micrograph of pure epoxy resin composites demonstrating the brittle property of pure epoxy resins with glassy and river lines reveals appear in the fractured surface of the epoxy resins. Small and sharp marks were opened in the direction of the crack propagation [19]. With introduction of the DW fillers into the epoxy resins, the morphologies structure of the fractured surfaces changed from glassy exterior to the rough surface of the fractured surface. The DW fillers were well dispersed and distributed within the epoxy resin. It can be seen numerous pull-out fibers at Figure 19 (B) and (C). Figure 19 (G) illustrate a bunch of polymers and patches showing low fillers dispersion within the epoxy matrix. The voids illustrate the poor bonded interfacial area between the filler and epoxy matrix that causes brittle deformation of the composites [20]. Figure 19 (D), (E) and (F) illustrates numbers of breaking fibers which indicate the better adhesion between the fillers and epoxy resin. Figure 19(D), (E) and (F) observed that mechanical properties of the composites had the higher properties in terms of strength.

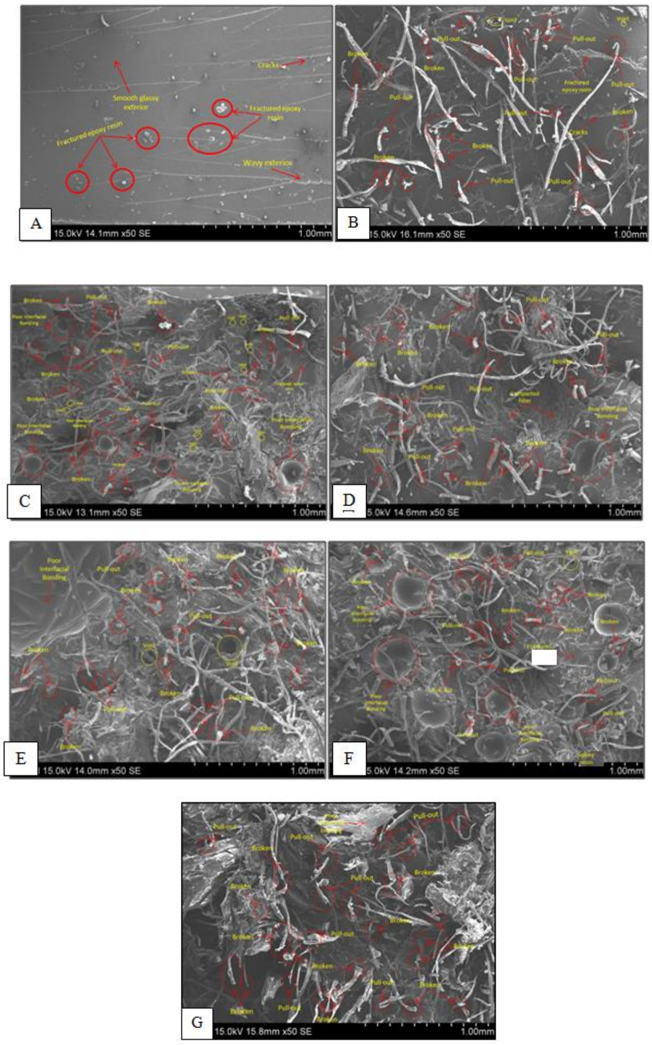

Figure 19: SEM analysis of fractured sample in 50x image magnification; (; (A) Control Sample, (B) Ratio of 0.1 DW, (C) Ratio of 0.2 DW, (D) Ratio of 0.3 DW, (E) Ratio of 0.4 DW, (F) Ratio of 0.5 DW, (G) Ratio of 0.6 DW

V. CONCLUSIONS

In this study, diapers waste were used as reinforcement as filler in epoxy matrix in order to investigate their mechanical and morphological properties. The results revealed that the introduction of DW in the epoxy resin matrix as composites materials improves the mechanical strength. Ratio 0.4 of DW in the epoxy composites indicated the optimum content for partition panel application with having the higher strength of tensile, flexural, impact and compressive than others. The analysis of the fractured surface morphologies showed relatively less pull out fibers, broken fibers shows the strength of the DW/epoxy composites and less void content in the composites which administrated the higher performance and improved properties of the composites compared to the rest of the ratio of the DW fillers. This study reveals that potential of DW fillers for industrial lightweight engineering applications and constructional panels.

VI. ACKNOWLEDGEMENTS

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NurAthirahHuzaishamwas born in Melaka, Malaysia in 1995. She is currently a second-year master's student in Faculty of Engineering Technology at UniversitiTun Hussein Onn Malaysia (UTHM), in Johor. She graduated from UTHM in bachelor's degree in Mechanical Engineering Technology (Textile Industry) in 2018. She has been awarded the Best Postgraduate Student Award in Community Social Responsibility in 2019. Her current master's research focuses on utilizing waste banana peel to produce biodegradable plastics. This project had won her 3 Gold Medals in Research and Innovation Technology Competition (RITEC 2019), International Research and Symposium and Exposition (RISE 2019) and National Innovation and Invention Competition (NIICe 2019). As a master's research student, she has published one SCOPUS indexed paper for TEST

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