Development And Characterization Of Polyethylene Terephthalate (PET) And Liquid Crystal Displays (Lcds) Waste Composite

Malik Daniyal Zaheer, Saeed Badshah, Rafiullah Khan, Muhammad Amjad, Sajjad Ahmad

Abstract: Recycling of materials can play an important role in sustainable environment and in the development of economy. In accordance with this generalized sustainable practice, the feasibility study of using non-metallic fractions (NMFs) from waste liquid crystal displays (LCDs) with waste polyethylene terephthalate (PET) bottles to produce a valuable composite material was carried out. Different composition of LCD-PET composite material was investigated in terms of mechanical strength properties and examination of composite fracture surfaces. The acquired results showed that the mechanical properties such as tensile strength, bending strength, impact strength and modulus of LCD-PET composites is improved by increasing of NMFs of LCDs. The optimum results of mechanical strength properties reflected in morphologies of fractured surface was obtained at 70 %wt of NMFs. At optimized weight ratio of NMFs in LCD-PET composite samples, tensile strength (0.46 MPa), tensile modulus (0.35 MPa), bending strength (2.09 MPa), bending modulus (14.15 MPa) and impact energy (0.74 J) was achieved. The improved value of these properties are due to strong adhesion bonding between particles of NMF and PET. This research suggests that the utilization of NMFs of waste LCDs with PET will result in the substantial reduction of environmental pollution.

Keywords: Adhesion Bonding, Composites, Non-metallic fractions, Polyethylene terephthalate, Recycling, Waste liquid Crystal Displays, Weight ratio

1 INTRODUCTION

Electrical and Electronics equipment's (EEE) are one of the most useable and valuable product in this century. Liquid Crystal Displays (LCDs) are most useful and needed product in the Electrical and Electronics equipment's (EEE) [1]. The LCDs are mostly composed of metals, plastic, PCBs, glass, cables and lamps [2]. The plastics (ABS, PC, HIPS, PP), acrylic glass, LCD module (thin film transistors, polarizers) used in LCDs [3]. The non-metal fraction of LCDs about 70% are reported that is huge in amount to recycled them [4]. The fiber glass, polarizer, diffusers and thermoset resin with reinforcing material are the major parts of non-metallic fractions of LCDs [5]. The chemical reactions of thermoset resins are difficult to melt and impossible to use it again by the present technologies and hence these are wastage or make pollution on lands [6]. According to China Star Optoelectronics Technology (CSOT), 16.79 million m2 LCDs produced in 2017 approximately. The production of LCDs increases 4% in every year throughout the world [7]. 683.5 million units of LCDs are manufactured across the world till 2016 and expected increased till 2021 is 217 million m2 [8]. In Pakistan 327 tons of waste LCDs are imported from 2011-2014 and its demand is increasing gradually per year [9]. In China, the estimated e-waste was 5.52 million tons in 2013 and 11.7 million tons in 2020 and expected increases is 20 million tons in 2040 [10]. The LCD e-waste increases globally per year and two times faster than other e-waste and it could be 52.2 million metric tons in 2021 [11]. The heavy toxic like polycyclic aromatic hydrocarbons (PHAs), polychlorinated biphenyls (PCBs) and polychlorinated dioxins (PCDs) are dangerous for the environment during incineration process [12]. The combustion of e-plastic leak toxic gases like polybrominated dibenzodioxinss to the environment that are harmful for health [13, 14].
The physical method for the recycling of non-metallic fractions (NMFs) is preferred instead of using any chemical process for dismantling of LCDs components [24]. The non-metallic fractions of waste LCDs used in different polymer composite to improve their mechanical and chemical properties and it also improves the strength of concrete as a binder ratio and provides better temperature sustainability to composite material [16, 17]. The different ratio of waste plastic LCDs combined together to develop a composite material with high strength [18]. The tensile and flexural strength of acrylonitrile butadiene styrene (ABS)- Polycarbonate (PC) composite material increases with the increase of Polycarbonate (PC) [19]. The cement mortar developed with waste plastic in which acrylonitrile butadiene styrene (ABS) show high flexural strength as compared to other waste plastic such as polycarbonate (PC), polyoxy-methylene (POM) and polyethylene terephthalate (PET) [20]. The powder form of waste liquid crystal glass used in cement mortar as a cement replacement for binding ratio [21]. The polyethylene terephthalate (PET) used as filler in different composite material such as coarse aggregate and sand binder ratio in cement to improves the strength of materials [22, 23]. The waste polyethylene terephthalate (PET) with 40 %wt sawdust produced a composite material at high modulus of elasticity [24]. The different ratios of virgin polyethylene terephthalate and recycled polyethylene terephthalate used for development of blends and showing high tensile strength in different ratios [25]. The PET fiber-gypsum composite developed from different particles sizes of recycled polyethylene terephthalate fibers and gypsum. The particle size 3.3 mm of recycled polyethylene terephthalate (rPET) have high mechanical strength properties [26]. The main objective of this study is to investigate the mechanical properties of non-metallic fractions of waste LCDs with recycled polyethylene terephthalate (PET) bottles. PET bottles are used as packing for various commercial products because of their light weight, high strength and low cost production [37]. The annual global production of polyethylene terephthalate (PET) bottles is 27.64 million tons in 2018. China is the biggest producer and

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consumer of polyethylene terephthalate (PET) bottles across the globe since 2014. In 2016, china produced 70 billion polyethylene terephthalate (PET) bottles for packing material. The production of polyethylene terephthalate (PET) bottles is about one million per min across the world and estimated waste of polyethylene terephthalate (PET) bottles is half a trillion per year [28, 29]. Powder metallurgy is the one of the promising techniques to avoid agglomeration and clustering of reinforcement during casting [30,31,32] The large amount of waste liquid crystal displays (LCDs) and polyethylene terephthalate (PET) bottles are everywhere in the world due to the most needed products in this era. Recycling of both the products plays an essential role for domestic use. Non-metallic fractions (NMF) of waste liquid crystal display (LCDs) with recycled polyethylene terephthalate bottles (PET) has the potential for development of composite material having good physical and mechanical strength while also as a resource of recycling and green environment.

2 Materials and Method

2.1 Preparation of NMFs of waste LCDs and Recycled PET

Waste LCDs were obtained from the local market and were washed for cleaning and then dried for one day. The components (PCB circuit, screws, electrical chips, diffuser foils, and reflective sheets) were manually separated from waste liquid crystal displays (LCDs). The rest of the remaining non-metallic fractions (NMFs) includes plastic, polarizer, liquid crystal glass panel and acrylic light guided plate (PMMA). These non-metallic fractions (NMFs) were crushed by electric crusher machine to get a valuable product in the form of small particles. The particle size 150 µm of liquid crystal glass panel, polarizer and acrylic glass plate (PMMA) were collected through vibratory sieve shaker (RETSCH AS 300). The size of plastic material (ABS, HIPS, PC and PP) was 5000 µm collected through crusher machine. PET bottle flakes was obtained from the local scarp recycler and the size of flakes was 3000 µm. No chemical treatment was done before and after NMFs of LCDs and PET bottle flakes.

2.2 Preparation of LCD-PET Composites

Different ratios of NMFs of LCDs and PET were melted together through external electric heating system in the range of 200°C to 250°C for 30 min. The upper and lower plate of mold were covered through aluminum foil to avoid the composite plate from breaking and sticking with the mold. The 400gm material was melted to achieve required product. The melted material put into the mold with subsequent application of pressure 1.55 kPa for 20 min. The mold was cooled at the room temperature under the same constant pressure. The composite samples (172 x 172 x 4mm) were prepared after the whole procedure and for further analysis. The weight of each LCD-PET composite plate was 150 gm. NMFs of LCDs with ratios of 30 %wt, 40 %wt, 50 %wt and 70 %wt mixed with recycled PET particles. Three composite plates were made in each formulation. The ratios used for the composition of LCD-PET material is shown in Table 1.

Table 1. *Different ratios of NMFs of LCDs and PET for formulation of LCD-PET composite material.*

Samples	Waste Liquid Crystal Displays		PET Bottles	Total Weightage
	Liquid crystal glass panel, polarizer & acrylic glass (PMMA) Weightage %	Plastic ABS, HIPS, PC and PP Weightage %	Weightage %	(gm)
LCD30% PET70%	10	20	70	150
LCD40% PET60%	10	30	60	150
LCD50% PET50%	10	40	50	150
LCD70% PET30%	10	60	30	150

3 Testing

All test specimens were cut into standard shapes from composite plates as shown in Figure 1. Universal Testing Machine (SHIMADZU 20KN) was used for tensile and bending strength. Charpy impact instrument is used for impact strength of composite material.

Figure 1. *LCD-PET composite plate formed from NMFs of LCDs and PET contents.*

3.1 Tensile Test

The specimens for tensile testing were cut from composite plates as shown in Figure 2. The specimen's dimensions were according to ASTM D638-03 standard [33]. The gauge length of specimens was 57 mm. The test speed with constant strain rate of 1mm/min was used. In each formulation, three specimens were tested to find the average tensile strength. The tensile specimens were gripped in machine for testing as shown in Figure 3. The uniaxial load was applied until the specimen breaks as shown in Figure 4 and generated the stress vs strain curve for tensile strength.

Figure 2. *Specimens prepared from LCD-PET composite plate for tensile testing.*

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Figure 3. *Specimen gripped in UTM.*

Figure 4. *Specimen break under load during tensile testing.*

3.2 Bending Test

Three-point bending tests for LCD-PET composites were carried out using universal testing machine (SHIMADZU 20KN) as shown in Figure 5. The specimens were cut from composite plates according to ASTM D790 standard [34]. The speed with constant strain rate of 0.5 mm/min with a span of 70 mm was used for the test. The load was applied until the specimens break and stress vs strain curve was generated. Average stress vs strain curve of three specimens was determined in each formulation. The specimens of bending test is shown in Figure 6.

Figure 5. *Three-point bending test of each formulation of LCD-PET composite specimens.*

Figure 6. *Specimens prepared from LCD-PET composite plate for bending test.*

3.3 Impact Test

The Charpy impact tester was used for impact tests of LCD-PET composites as shown in Figure 7. The specimens were cut from composite plates according to ASTM D6110-10 standard [35]. The hammer was released from a certain height with the weight of 3.4 kg. The v-notch angle was 45° and the depth of the notch was 2mm. Three specimens in each formulation were tested and noted for the average value of specimens. The impact specimens are shown in Figure 8. Impact toughness was calculated by using equation [27].

$$I.S = E/A \tag{1}$$

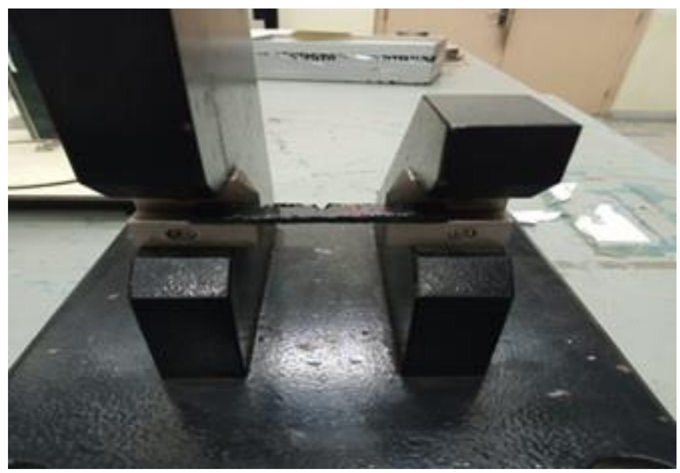

Figure 7. *Specimen on anvil of charpy apparatus for impact testing.*

Figure 8. *Specimens cutted from LCD-PET composite plate for impact testing.*

3.4 Scanning Electron Microscope (SEM)

The surface characteristics of LCD-PET composite material was investigated with the use of KYKY-EM6900 Tungsten Filament scanning electron microscope. The fractured surface monographs of composite specimens were taken after the tensile, bending and impact test. For conduction, the analysis fracture specimens with silver paste on the edges and were put on stub with carbon tape. The analysis surface of specimens that was investigated covered with a gold coating and SEM used with an accelerated voltage of 15kV and the monographs were captured in vacuum.

4 Results and Discussions

4.1 Tensile Test Results

The tensile properties of LCD-PET composite formulation were tested on universal testing machine. The results of tensile strength and tensile modulus with different ratios of LCD-PET composite material as shown in Table 2. The tensile strength of LCD-PET composites increases with the increase of NMFs of LCDs as shown in Figure 9. The 70 %wt NMFs of LCDs has given the higher tensile strength and modulus value. The value of tensile strength and modulus decreases with the decreases of NMFs weight ratio due to difficulty of particles adhesion in composites material. At 70 %wt NMFs, the tensile strength and modulus values obtained are 0.46 MPa and 0.35 MPa respectively. The maximum value of 70 %wt NMFs due the filling of all available gaps by strong adhesion bonding with PET has given the good strength of LCD-PET composites during tensile test. The low tensile strength and modulus value at 70 %wt PET is due to low mechanical properties of PET as compared to NMFs of LCDs and low adhesion bonding in particles of LCD-PET composites. Stress -strain curves are non-linear for all cases, however non-linearity is more obvious in the higher PET content specimens. Some local abrupt variation in the curves is seen which may be attributed to the debonding of the composite phase.

Table 2. *Tensile strength and modulus of LCD30%-PET70%, LCD40%-PET60%, LCD50%-PET50% and LCD70%-PET30% composite material.*

Composite Material	Peak Load (N)	Ultimate Tensile Strength (MPa)	Tensile Modulus (MPa)
LCD30% PET70%	28.8	.20	.07
LCD40% PET60%	37.4	.25	.20
LCD50% PET50%	42.2	.29	.32
LCD70% PET30%	67.3	.46	.35

The tensile strength of LCD-PET composite withstand load of 67.3 N at 70 %wt NMFs weight fraction and higher withstand load of LCD-PET composite as compared to other composite materials. The tensile strength of other LCD-PET composites with different NMFs 0f 30 %wt, 40 %wt and 50 %wt withstand load of 28.8, 37.4 and 42.2 N respectively. The strong bonding between particles of LCD-PET composite with the increase of NMFs of LCDs weight ratio and increases of PET ratio decreases the strength of LCD-PET composite material. The

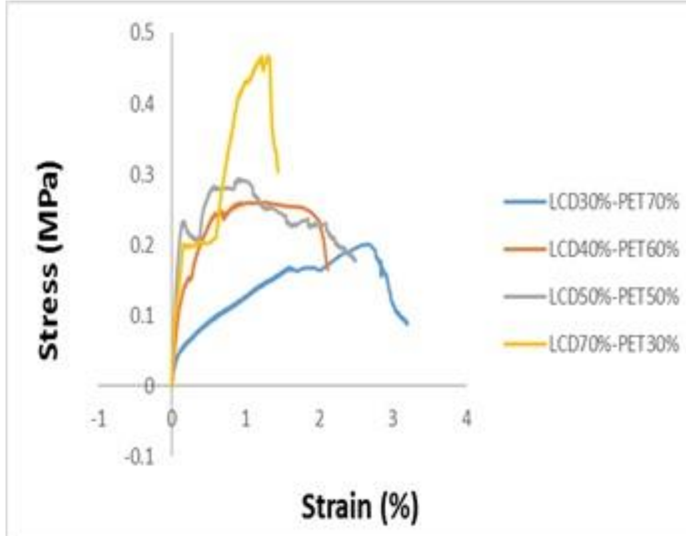

Figure 9. *Comparison of stress-strain graph for tensile strength of LCD30%-PET70%, LCD40%-PET60%, LCD50%-PET50% and LCD70%-PET30% composite material.*

increase in non-metallic fractions also increases the tensile strength of composite material as shown in Figure 10. An exponential increase in the strength of the composite with increasing LCD content is evident from the graph.

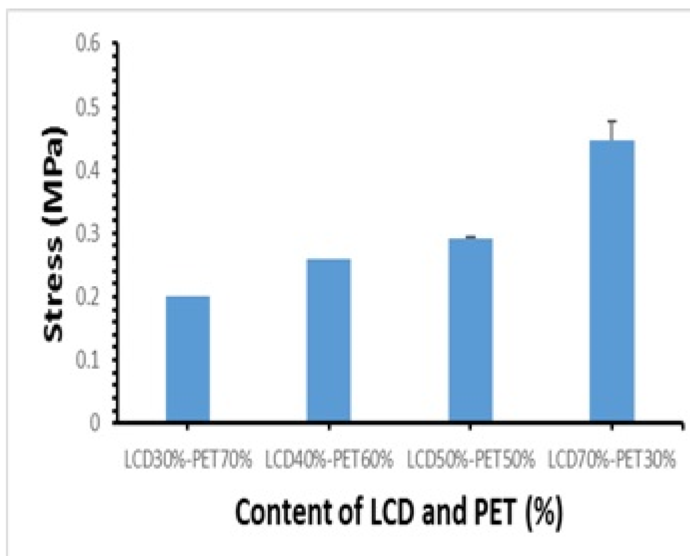

Figure 10*. Average variation of tensile strength of specimens in each formulation.*

4.2 Bending Test Results

LCD-PET composite of different weight ratios were analyzed in bending test. The bending properties of LCD-PET composite material as shown in Table 3. The variation in values of bending strength and modulus with different NMFs ratio of LCDs with PET can be clearly observed in Figure 11. The increase of bending strength in LCD-PET composite with the increase of NMFs of LCDs. The maximum value of bending strength and modulus was recorded 2.09 MPa and 14.15 MPa respectively at 70 %wt NMFs of LCDs and minimum value at 30 %wt NMFs of LCDs. The strong adhesion bonding between particles of LCD-PET composite at 70 %wt NMFs of LCDs. The increase of PET weight ratio in LCD-PET composite decreases the bending strength due to the difficulty of bonding in particles and effecting the mixture and weak zones producing in specimens for failure and later confirmed by SEM monographs results. The bending strength of NMFs of LCDs ratios 30 %wt, 40 %wt and 50 %wt was 0.38, 0.58 and 1.32 MPa with PET. At 70 %wt NMFs provided the good results as compared to other ratios during bending test.

*.**Table 3**. Bending strength and modulus of LCD30%-PET70%, LCD40%-PET60%, LCD50%-PET50% and LCD70%-PET30% composite material*

Composite Material	Peak Load (N)	Ultimate Bending Strength (MPa)	Bending Modulus (MPa)
LCD30% PET70%	3.8	.38	2.27
LCD40% PET60%	5.7	0.58	2.34
LCD50% PET50%	12.9	1.32	3.71
LCD70% PET30%	20.5	2.09	14.15

The bending strength of LCD-PET composite at 70 %wt NMFs of LCDs withstand of higher load 20.5 N. The LCD-PET with NMFs of LCDs ratio 30 %wt, 40 %wt and 50 %wt withstand of load 3.8, 5.7 and 12.9 N. The increasing and decreasing NMFs of LCDs and PET in LCD-PET composite as shown in Figure 12. The strength of LCD-PET composite material increases with the increase of NMFs and decreases with the increase of PET.

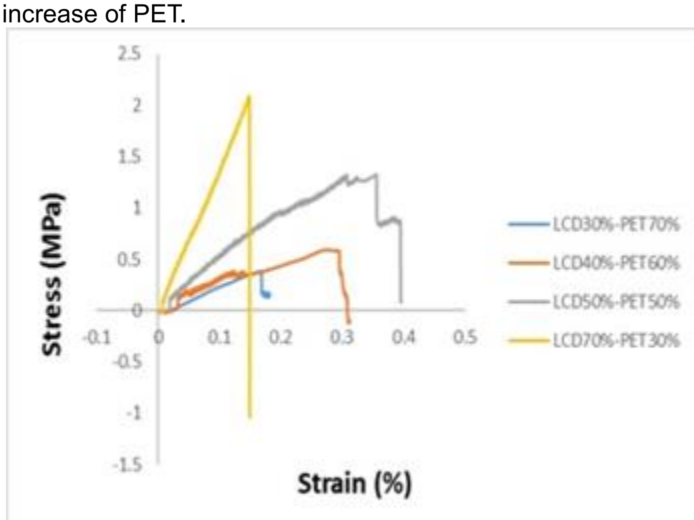

***Figure 11**. Comparison of stress-strain graph for bending strength of LCD30%-PET70%, LCD40%-PET60%, LCD50%-PET50% and LCD70%-PET30% composite material.*

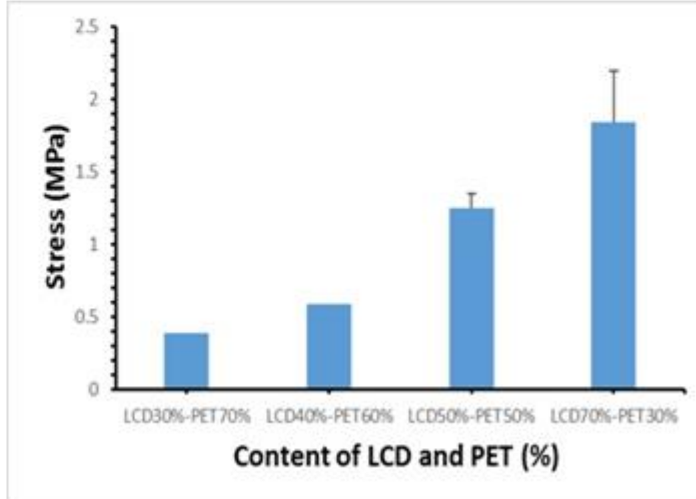

***Figure 12.** Average variation of bending strength of specimens in each formulation.*

4.3 Impact Strength

The LCD-PET composite of different weight ratio of NMFs of LCDs were analyzed for impact strength. The LCD-PET composites have high impact strength with the increase of NMFs of LCDs. Figure 13 shows an approximately linear increase of impact energy with LCD content. This behavior is somewhat different than tensile properties where an exponential increase was observed. The high impact strength of composite at 70% weight ratio of NMFs as compared to other LCD-PET composite materials and higher impact energy was recorded 0.74J. The reason behind this impact strength increasing and decreasing due to adhesion bonding as same postulated in the discussion of tensile strength and bending strength. The impact energy of NMFs with ratio of 30 %wt, 40% and 50% were 0.24J, 0.37J and 0.54 J respectively. The increasing of PET reducing the strength of composite material and 70 %wt NMFs in LCD-PET composites gives better strength than others during impact test.

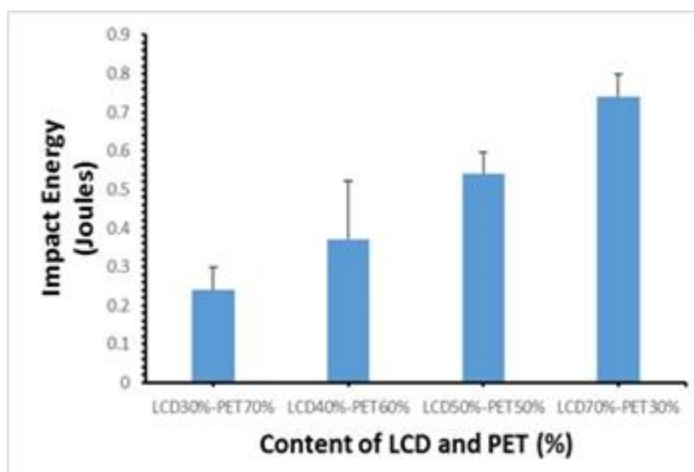

***Figure 13.** Comparison of Impact energy of LCD-PET composite formulations and also average variation of specimens in each formulation of LCD-PET composite material.*

4.4 Morphology of Fracture Surface

SEM images of fracture surfaces of LCD-PET composite specimens (after tensile test) were obtained out to study the distribution of NMFs /PET interaction and the roughness of specimens fractured surface. Figure 14(a) and (b) shows the SEM image of LCD-PET composite having 70 %wt NMFs and 30 %wt of PET particles. The NMFs of LCDs were seen along with glass fibers and thermoset resins. The particles of NMFs in composite material surface was nearly uniform that affected the surface structure and strength. Figure 14 (a) shows the smooth surface as compared to LCD-PET composites (Figures 15 b, 16 a and 17 a) due to good adhesion bonding and interlocking of particles The voids and gaps were absent throughout the composite material due to good adhesion bonding between particles as shown in Figure 14 a and b.

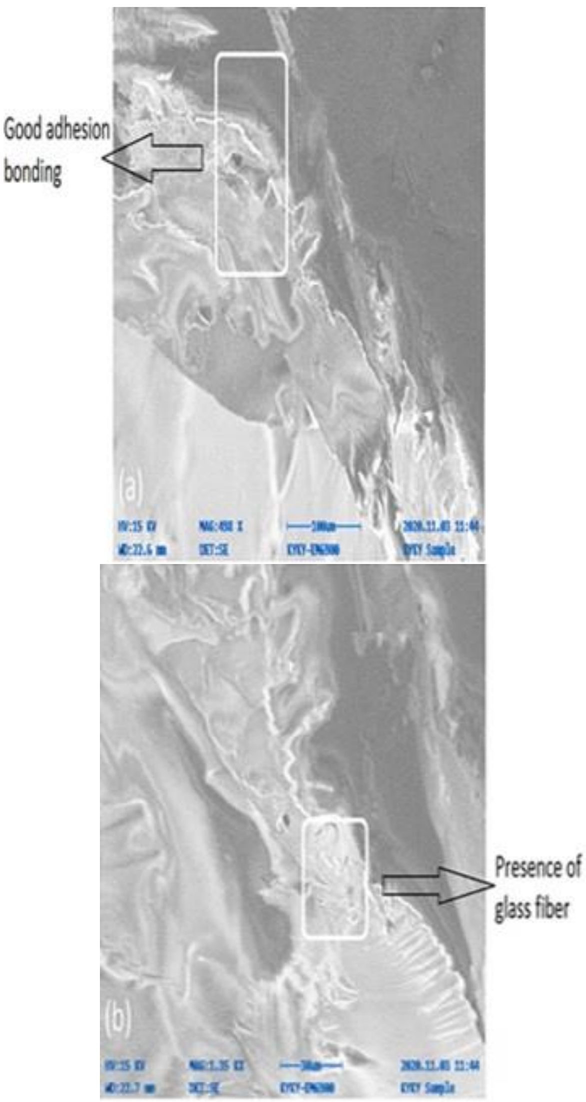

Figure 14. *SEM image of fracture surface of LCD70%-PET30% (a) fracture surface MAG: 498 X (b) fracture surface MAG: 1.35 KX.*

The SEM image of fractured surface of LCD-PET composite having 50 %wt NMFs of LCDs as shown in Figure 15 a and b respectively In Figure 15 a, the composite material provided good strength as compared to 30 %wt and 40 %wt NMFs due to presence of wavy surface and due to absence of fiber pull-out. . In Figure 15 b NMFs of LCDS were clearly seen with some with some amount of glass fibers. Figure 15 shows the good dispersion of particles of NMFs throughout the composite material provide homogenous properties and reinforcement between particles of LCD-PET composite and low adhesion bonding as compared to LCD-PET composite material having 70 %wt non-metallic fractions (NMFs) of LCDs (Figure 14).

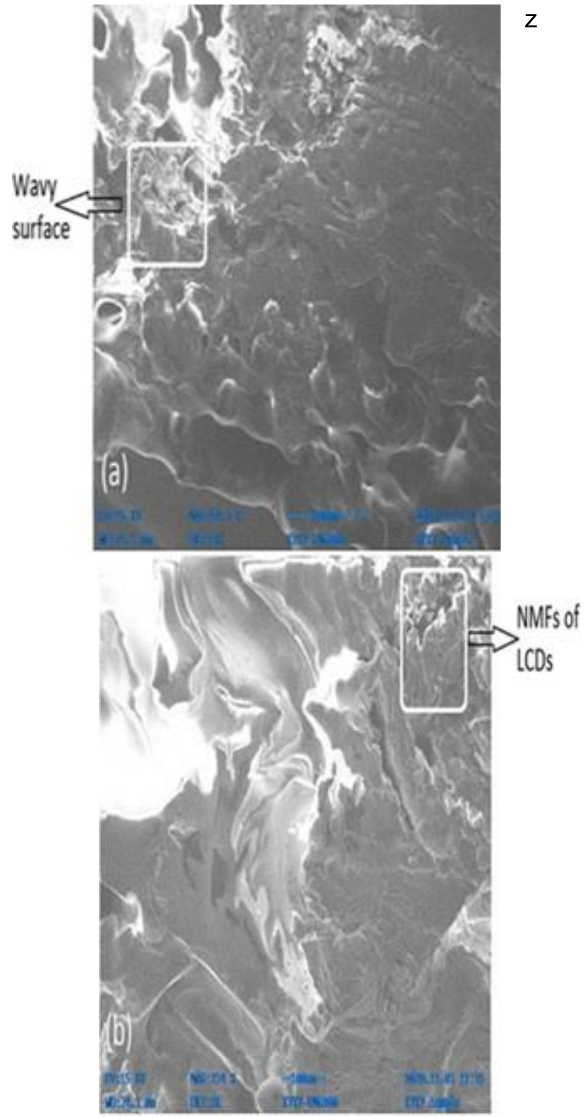

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Figure 15. *SEM image of fracture surface of LCD50%-PET50% (a) fracture surface MAG: 54.7 X (b) fracture surface MAG: 274 X.*

Figure 16 (a) and (b) shows the fractures surface of LCD-PET composite having 40 %wt NMFs of LCDs. It can be seen that the sharp edges of PET fiber in the material and the presence of fiber pull-out and voids due to poor adhesion bonding between the particles in the matrix and reinforcement of LCD-PET composite. These figures shows that higher PET ratio in LCD-PET composites reduces the strength of fiber and also effect the mixture of LCD-PET composite material.

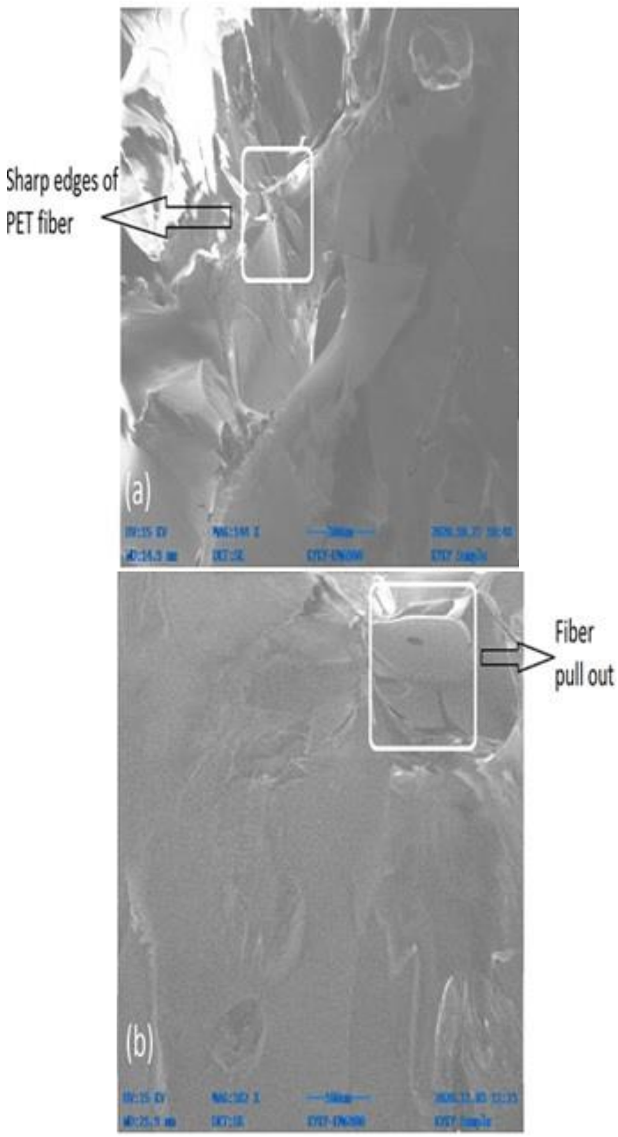

Figure 16. *SEM image of fracture surface of LCD40%-PET60% (a) fracture surface MAG: 144 X (b) fracture surface MAG: 382 X.*

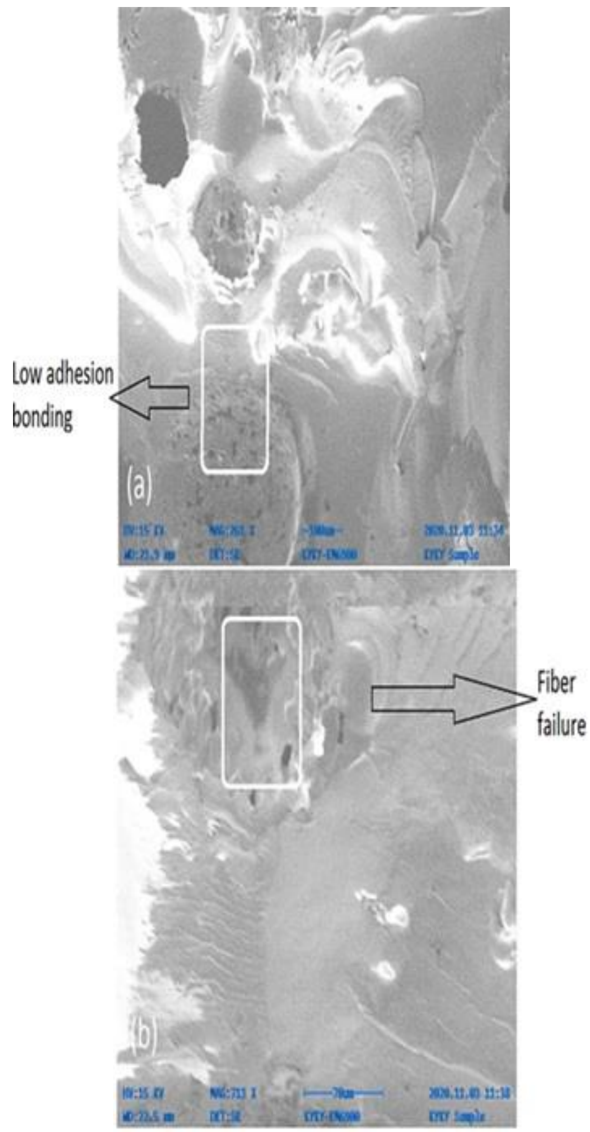

Figure 17*. SEM image of fracture surface of LCD30%-PET70% (a) fracture surface MAG: 261 X (b) fracture surface MAG: 713 X.*

In Figure 17 (a) and (b), it can be clearly seen that the LCD-PET composite having 30 %wt NMFs of LCDs had large rapture holes in fracture surface of composite material due to poor adhesion bonding and reinforcement between particles and fiber failure due to presence of voids. In Figure 17 (a) fracture surface of composite material seemed to be rougher and irregular distribution of particles in higher weight ratio of polyethylene terephthalate (PET). In Figure 17 (b) fiber failure can be clearly seen in composite material that effects the mechanical strength properties and PET fibers more in content as compared to other composite materials.

5 Conclusion

In this study a composite material was developed using waste NMFs of LCDs and PET contents. The material was formed in a mold by co-melting of the contents and by pressing in a mold. The developed material was tested for tensile properties, impact and bending strength according to standard test procedures. Tensile and bending strength were exponentially increased with NMFs of LCDs content. The impact energy increase was linear with NMFs of LCDs content. Stress-strain curves were more non-linear for higher PET content and large deformation was observed before failure. SEM analysis revealed good adhesion boding of NMFs of LCDs and PET contents at higher NMFs of LCDs ratios with a lower void. However, voids volume fractions were more for higher PET ratios which resulted in lower strength and modulus.

REFERENCES

[1] J. Cui, N. Zhu, Y. Li, D. Luo, P. Wu, and Z. Dang, "Rapid and green process for valuable materials recovery from waste liquid crystal displays," Resources, Conservation and Recycling, vol. 153, p. 104544, 2020.

[2] A. Ryan, L. O'Donoghue, and H. Lewis, "Characterising components of liquid crystal displays to facilitate

disassembly," Journal of Cleaner Production, vol. 19, no. 9-10, pp. 1066-1071, 2011.
[3] M. L. Socolof, J. G. Overly, and J. R. Geibig, "Environmental life-cycle impacts of CRT and LCD desktop computer displays," Journal of Cleaner production, vol. 13, no. 13-14, pp. 1281-1294, 2005
[4] A. Amato and F. Beolchini, "End of life liquid crystal displays recycling: A patent review," Journal of environmental management, vol. 225, pp. 1-9, 2018.
[5] J. Felix, W. Letcher, H. Tunell, K. Ranerup, T. Retegan, and G. Lundholm, "P-61: Recycling and Re-Use of LCD Components and Materials," in SID Symposium Digest of Technical Papers, 2010, vol. 41, no. 1: Wiley Online Library, pp. 1469-1472.
[6] P. Tarantili, A. Mitsakaki, and M. Petoussi, "Processing and properties of engineering plastics recycled from waste electrical and electronic equipment (WEEE)," Polymer Degradation and Stability, vol. 95, no. 3, pp. 405-410, 2010.
[7] C. Yang, "State-led technological innovation of domestic firms in Shenzhen, China: Evidence from liquid crystal display (LCD) industry," Cities, vol. 38, pp. 1-10, 2014.
[8] L. Yu et al., "Environmental Impact Assessment on the Recycling of Waste LCD Panels," ACS Sustainable Chemistry & Engineering, vol. 7, no. 6, pp. 6360-6368, 2019.
[9] M. Imran, S. Haydar, J. Kim, M. R. Awan, and A. A. Bhatti, "E-waste flows, resource recovery and improvement of legal framework in Pakistan," Resources, Conservation and Recycling, vol. 125, pp. 131-138, 2017.
[10] J. Li, J. Yang, and L. Liu, "Development potential of e-waste recycling industry in China," Waste Management & Research, vol. 33, no. 6, pp. 533-542, 2015.
[11] A. Akcil, I. Agcasulu, and B. Swain, "Valorization of waste LCD and recovery of critical raw material for circular economy: A review," Resources, Conservation and Recycling, vol. 149, pp. 622-637, 2019.
[12] R. Wang and Z. Xu, "Recycling of non-metallic fractions from waste electrical and electronic equipment (WEEE): a review," Waste Management, vol. 34, no. 8, pp. 1455-1469, 2014.
[13] M. Bientinesi and L. Petarca, "Comparative environmental analysis of waste brominated plastic thermal treatments," Waste Management, vol. 29, no. 3, pp. 1095-1102, 2009.
[14] J. K. Chan et al., "Body loadings and health risk assessment of polychlorinated dibenzo-p-dioxins and dibenzofurans at an intensive electronic waste recycling site in China," Environmental science & technology, vol. 41, no. 22, pp. 7668-7674, 2007.
[15] X. Zhuang, W. He, G. Li, J. Huang, and Y. Ye, "Materials Separation from Waste Liquid Crystal Displays Using Combined Physical Methods," Polish Journal of Environmental Studies, vol. 21, no. 6, 2012.
[16] M. Y. Abdellah, H. I. Fathi, A. M. Abdelhaleem, and M. Dewidar, "Mechanical properties and wear behavior of a novel composite of acrylonitrile–butadiene–styrene strengthened by short basalt fiber," Journal of Composites Science, vol. 2, no. 2, p. 34, 2018.
[17] S. K. Kim, S. T. Kang, J. K. Kim, and I. Y. Jang, "Effects of particle size and cement replacement of LCD glass powder in concrete," Advances in Materials Science and Engineering, vol. 2017, 2017.
[18] S. Lee, S.-S. Cho, S.-Y. Lee, J. L. Park, M. H. Hong, and H. S. Hong, "Effects of PE (Polyethylene) and GF (Glass Fiber) Addition on Tensile Strength and Elongation of ABS (Acrylonitrile Butadiene Styrene) Recovered from Waste LCDs," Journal of the Korean Institute of Resources Recycling, vol. 22, no. 3, pp. 50-56, 2013.
[19] R. Krache and I. Debbah, "Some mechanical and thermal properties of PC/ABS blends," Materials Sciences and Applications, vol. 2, no. 5, pp. 404-410, 2011.
[20] G. Kaur and S. Pavia, "Physical properties and microstructure of plastic aggregate mortars made with acrylonitrile-butadiene-styrene (ABS), polycarbonate (PC), polyoxymethylene (POM) and ABS/PC blend waste," Journal of Building Engineering, p. 101341, 2020.
[21] H.-Y. Wang, "A study of the effects of LCD glass sand on the properties of concrete," Waste Management, vol. 29, no. 1, pp. 335-341, 2009.
[22] R. T. Nirina, T. Sekito, and A. J. Oliva, "Recovery of Post-Consumer PET Bottles in a Composite Material Preparation," International Journal of Chemical and Molecular Engineering, vol. 13, no. 6, pp. 323-326, 2019.
[23] M. J. Islam, M. S. Meherier, and A. R. Islam, "Effects of waste PET as coarse aggregate on the fresh and harden properties of concrete," Construction and Building Materials, vol. 125, pp. 946-951, 2016.
[24] K. S. Rahman, M. N. Islam, M. M. Rahman, M. O. Hannan, R. Dungani, and H. A. Khalil, "Flat-pressed wood plastic composites from sawdust and recycled polyethylene terephthalate (PET): physical and mechanical properties," SpringerPlus, vol. 2, no. 1, p. 629, 2013.
[25] J. H. Lee, K. S. Lim, W. G. Hahm, and S. H. Kim, "Properties of recycled and virgin poly (ethylene terephthalate) blend fibers," Journal of Applied Polymer Science, vol. 128, no. 2, pp. 1250-1256, 2013.
[26] S. Erdem and N. Arioglu, "An analysis of the properties of recycled PET fiber-gypsum composites," ITU A, no. 14, pp. 91-101, 2017.
[27] L. N. Ji, "Study on preparation process and properties of polyethylene terephthalate (PET)," in Applied Mechanics and Materials, 2013, vol. 312: Trans Tech Publ, pp. 406-410.
[28] Y. Gu et al., "Environmental performance analysis on resource multiple-life-cycle recycling system: Evidence from waste pet bottles in China," Resources, Conservation and Recycling, vol. 158, p. 104821, 2020.
[29] Y. Wang et al., "Performance simulation and policy optimization of waste polyethylene terephthalate bottle recycling system in China," Resources, Conservation and Recycling, vol. 162, p. 105014, 2020.
[30] Asghar, Z.; Zahid, G.; Ahmad, E.; ud Din, R.; ul Haq, M.N.; Subhani, T.; Hussain, Z.; Badshah, S. Effect of particle morphology and coating thickness on fluorescent behavior of Ce doped yttrium aluminium garnet phosphor screens. Journal of Materials Science: Materials in Electronics 2015, 26, 6744-6749
[31] Asghar, Z.; Zahid, G.; Rafi-ud-Din; Ahmad, E.; Mehmood, M.; Badshah, S. Effect of degassing parameters on sinterability of Al/B4C powder mixture. Powder Metallurgy 2015, 58, 36-40.
[32] Asghar, Z.; Latif, M.A.; Rafi-ud-Din; Nazar, Z.; Ali, F.; Basit, A.; Badshah, S.; Subhani, T. Effect of distribution of B4C on the mechanical behaviour of Al-6061/B4C composite. Powder Metallurgy 2018, 61, 293-300.

[33] M. A. Al-Shammri and S. E. Abdullah, "Experimental and numerical investigation of hyper composite plate structure under thermal and mechanical loadings," Journal of Engineering, vol. 23, no. 8, pp. 56-69, 2017.
[34] H. Divya, H. Kavya, D. S. Bavan, and B. Yogesha, "Evaluation of Mechanical Properties of Wood Particles Reinforced Polymer Composites," 2018.
[35] C. Wang, S. Wang, H. Cheng, Y. Xian, and S. Zhang, "Mechanical properties and prediction for nanocalcium carbonate-treated bamboo fiber/high-density polyethylene composites," Journal of Materials Science, vol. 52, no. 19, pp. 11482-11495, 2017.
[36] I. Ajaj and M. Obaidi, "Effect of saw dust wood on some mechanical properties of recycled polyethylene terephthalate (RPET)," International Journal of Current Engineering and Technology, vol. 5, no. 1, pp. 20-26, 2015.