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Evaluation of tensile and flexural strength properties of virgin and recycled high-density polyethylene (HDPE) for pipe fitting application

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ABSTRACT

Innovative ways of eliminating heavy plastic waste all over the world must be designed and implemented via recycling of post used plastic materials by making new products. As a result of continuous use of plastic materials, adverse effect on the environment and economic issues had been a problem confronting the post-consumer recycling of these materials. High-Density Polyethylene (HDPE) polymers are widely being used and its products are preferable than metals having the properties such as lightweight, ease of manufacture, stronger and tough.

This research work focuses on investigating the flexural and tensile strength properties of virgin and recycled HDPE for pipe fitting application. The mixing of recycled with virgin HDPE were done at different weight percentages (0:100, 10:90, 20:80, 30:70, 40:60, 50:50, 60:40, 70:30, 80:20, 90:10, and 100:0). Eleven (11) T-reducer pipe fitting samples were produced via injection moulding machine. Data of flexural strength test for selective samples similar with tensile test in showed that 100 wt% virgin HDPE had 39.98 MPa whereas 100 wt% recycled HDPE had 20.88 MPa. Generally, all the mechanical (tensile and flexural) properties decreased as number of recycled contents increased. Because, recycled high density polyethylene scrap (*r*HDPE) have weaker bond strength than virgin high density polyethylene (*v*HDPE) materials. Bond strength is very strong in virgin HDPE, and they also have molecular weight that is large. Also, there is highest rigidity in virgin HDPE. Rigidity is very high in virgin HDPE due to high toughness. So, with lower load, bond strength is not allowed to break. But there is weaker bond strength in 100% recycled scraps of HDPE as a result of different kinds of stresses they have been subjected to during prior usage.

1. Introduction

Mixing and blending with virgin materials is one of the most useful methods for processing recycled polymers. This makes the production of the recycled polymers cost effective with enhanced properties. Properties such as low density, corrosion resistance, high strength and use friendly design have made thermoplastic polymers one of the sought-after materials compared to aluminium and other metals. The importance of density in a material cannot be overemphasized. The intrinsic strength of material can be linked to its density [1-9]. As reported by the authors, high-density polyethylene is widely used. This has caused a heavy plastic waste all over the world because consumers don't use high-density polyethylene for a longer period of time. Innovative ways of eliminating heavy plastic waste all over the world must be designed and implemented via recycling of post used plastic materials by making new products. The enhancement in mechanical properties may be low and not close to the fully virgin materials, therefore, it is not good to recycle products 100%.

Optimum strength can be achieved when recycled and virgin materials are blended or mixed in a definite ratio thereby decreasing the virgin raw material consumption and the process energy [10-14]. Sulyman et al. [10] investigated the improvement in the characteristics of polymers by using virgin polymers in asphalt. This has been achieved over the years. More interests have been shown recently in replacing commercial virgin material with recycled polymers. Moreover, the study of Atikler et al. [15] in getting

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rubber from waste tires has also been commended. Melt compounding had been used to make RHDPE and clay hybrids. Impact strength had been reduced by the addition of clay to RHDPE, but the tensile strength had been influenced little. MAPE content had slightly improved the tensile strength of RHDPE/Clay hybrid. However, with 5% addition of MAPE, the impact strength had increased significantly with 44%. As compared to when no MAPE was added to the hybrid. All the other mechanical properties remained the same except the impact strength when the hybrid was either prepared by the one-step or the two-step methods at 5% significance level. The thermal stability of RHDPE was reduced by the clay [16].

The feasibility of replacing recycled plastic with virgin plastic was also investigated by Siddique et al. [17]. This is done in order to compare the mechanical properties of using recycled HDPE as a replacement for virgin HDPE in the plastic industry. It has been reported in the literature that the tensile strength of virgin HDP is slightly better than the tensile strength of recycled HDPE. Moreover, the flexural strength difference is 8% between virgin and recycled HDPE. However, the compressive strength of recycled HDPE is better than that of virgin HDPE by 2.2 % and 3% by estimated value. In addendum, there is minimal adverse effect to the environment when recycled HDPE is used. Therefore, the mechanical properties of recycled HDPE are not different from the mechanical properties of virgin HDPE. It means the process of recycling has not adverse effect on the mechanical properties of recycled HDPE. It implies, using recycled HDPE in place of virgin HDPE is very cost effective and environmentally viable [14,15,18,19]. Recycling process brings cost effectiveness and eliminate waste of resources. Post-consumer content should be functionally and qualitatively equivalent to primary content and satisfy manufacturer demand that only primary material previously served. Recycled HDPE via hot pressing moulding had been used to produce composite panels. These panels showed excellent dimensional stability when compared to the panels made from virgin HDPE. Also, the flexural and tensile properties of the composite panels made from recycled HDPE corroborate with the properties exhibited by the panels made from virgin HDPE. Both mechanical properties and stability of the composite panels were significantly enhanced when 3–5 wt% of maleate polypropylene were added. The microstructural evolution of the composite panels with addition of MAPP showed a very strong and enhanced interfacial bonding. More improvement in the mechanical properties and dimensional stability can be achieved by polymer content increase and by coupling agent addition [14,20-22].

The aim of this research is to investigate the effect of recycled HDPE blending ratio on the tensile and flexural properties of HDPE polymer and to reduce the consumption of virgin material and environmental pollution. Moreover, this investigation will show which of the mixing ratio of recycled and virgin HDPE that are likely to improve the tensile and flexural strength properties, by comparing to the tensile and flexural strengths of virgin HDPE. This eventually would be selected as the optimum percentage of mixing ratio of recycled and virgin HDPE.

2. Methods and materials

Virgin high-density polyethylene (vHDPE) and recycled (rHDPE) materials were used for this experimental work and different proportions of the materials were mixed together according to their various volumes. Manufacturing of various products of plastic such as pipe uses virgin resin (vlack co-polymer). The manufacturing of the material was made in Saudi Arabia diameter of 3.0 mm particle size. Also, its density was 0.9 g/cm^3 as seen in Fig. 1. By using identification tag (type 2), wastes were sorted, and Recycled HDPE materials were obtained. This was followed by the crushing of these products into smaller particle sizes. The crushing changed the product into a pellet form which was made via the extrusion process and then the experimental procedure was carried out.

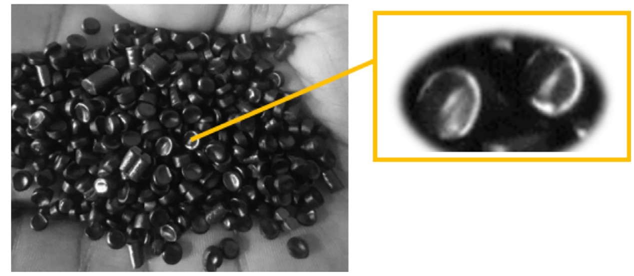

Fig. 1. Virgin HDPE raw material.

2.1. Collection and sorting

Different sources were used for the collection of Recycled HDPE materials. Post industrial waste and defect products were found on the scrap's storage. Manual sorting of the materials was employed because of ease of identification of code two HDPE.

2.2. Size reduction and shredding

The essence of first cutting and reducing the sizes of the HDPE materials was to make the crushing process very easy as seen in Fig. 2. Before, shredding, Jig saw, and band saw machines were used to reduce the sizes of the waste materials. These reduced materials through the means of feed hopper were fed into the mill throat as indicated in Fig. 2. As the machine shaft teeth rotated, the plastics entered the shredding machine mill, and the plastics were cut into smaller pieces (flakes). At the bottom of the shredder, there was a filter with diameter between 5 and 10 mm located there in order to get flakes that are uniform in size as seen in Fig. 2.

2.3. Washing and drying

In order to remove flake contamination, hot water was used to wash the waste HDPE materials within a temperature around 60 ^{0}C. Chemical washing was used to remove other minute contamination such as glue. Likewise, the plastic flakes were also washed with detergent and berekina. Before the extrusion process began, at room temperature, the flakes were dried for 2 days with the assistance of the sunlight.

2.4. Extrusion and pelletizing

The loading of the flakes was done into the hopper of the Extruder, and this was followed by melting. The screw function was to melt the flakes at different stages of temperature and also for flakes transportation. The thermoset was attached with temperature sensor in order to read the values of temperature at the stage of the screw. Fig. 3 shows the methodology used in this research and the plastic flakes extrusion process parameters.

2.5. Quality checking of rHDPE pellet

Impurities filtering can be done or removed from the plastic pellet by using the manufacturing process procedure. The quality check of the recycled HDPE pellet is a function of flowability and ash content amount.

Fig. 2. Suze reduction and Shredding of waste plastic.

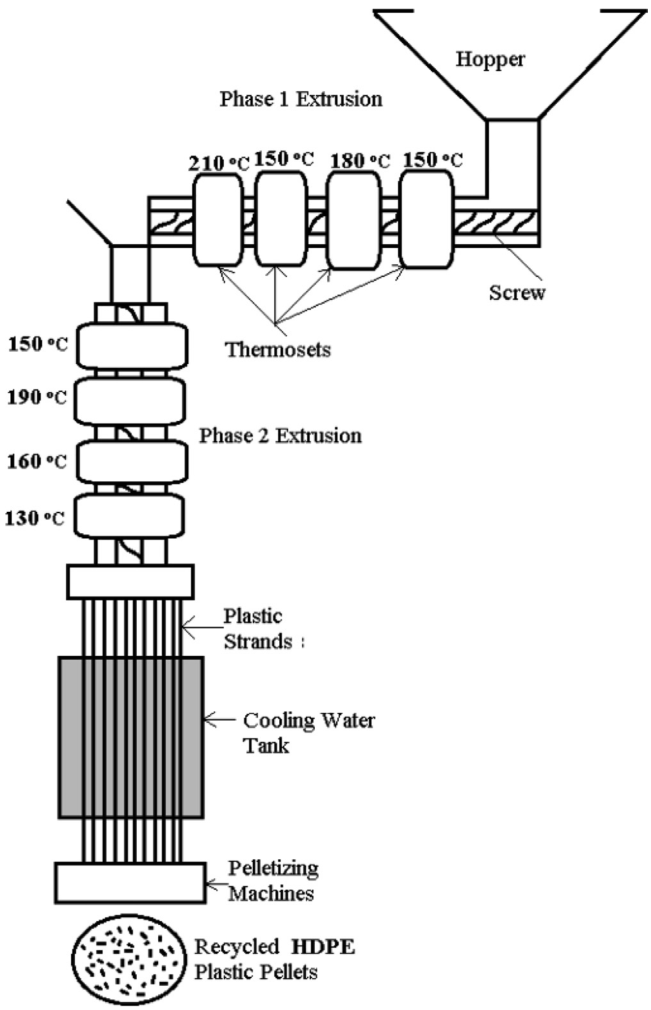

Fig. 3. Schematic diagram of recycled Pellet production process.

2.5.1. Ash content

Fig. 4 shows how the ash test was used to determine the total filler content. Though additional test would be required to determine multi-filled materials individual percentages. The weight percent of carbon black cannot be determined by the ash test. Because during the ash test, carbon disappears. ASTM D2584 standard procedure was used for this test.

The test was carried out using 12 g of sample. It means each crucible contained 4 g of samples and 3 crucibles were used. Table 1 reports the data for the 3 crucibles.

Fig. 4. Ash content test (a) Crucible in the furnace (b) measuring the mass of crucible and materials to be tested.

Sample 1 has 3.98% ash content. The material was made of different HDPE plastics having varied functions, colour and application.

2.6. Plastic production

The mechanical properties of the virgin HDPE were analyzed suing 11 samples. Some proportions of recycled HDPE were added to the virgin HDPE as stated aforementioned in their various ratios. Tests were carried out on other ratios 90/10, 80/20, 70/30, 60/40, 50/50, 40/60, 30/70, 20//80, 10/90, and 0/100 vHDPE/rHDPE ratio. The summary of all the tests carried out on the other ratios are seen in Table 2 with their average results of total material consumption.

Manufacturing of the samples occurred after the recycled HDPE pellet had been prepared. The digital weighing balance was used for the measurement of both the recuycled and virgin HDPE raw materials at different mixing ratios. The mixing of the virgin and recycle HDPE raw materials at specific ratio were necessary before loading the raw materials into the hopper. The loading and mixing of the raw materials were done for 15 min. Vacuum sucker was used to load the mixture of the virgin and recycled HDPE raw materials at a weight of 3 kg into the hopper. This produced 2 T-reducer HDPE fitting products. This includes the allowable scrap and the remaining materials on the screw. Fig. 5 shows the machine set up before the raw materials were fed into the hopper. The range of temperature for the injection machine between 210 and 230 degrees Celsius at the first phase of the screw to the position of the final phase of the end of nozzle. However, 212 degrees Celsius shows at the input screen as actual temperature at the first phase of the screw. While 231 degrees Celsius was for the nozzle end. The injection moulding cycle process was very short especially for T-reduce HDPE fitting.

Table 1
Ash content test results.

Temperature	600 °C			
Time	2 h			
Sample No.	Weight of Empty Crucible (gram)	With Sample weight (gram)	With Ash crucible weight (gram)	Mass of Ash (%)
1	71.2593	2.9062	71.3752	3.98
2	71.5852	2.2575	71.6823	4.30
3	70.7388	2.5626	70.8400	3.94
Average				**4.06**

Table 2
Composition ratio in gram (g) and percent (%).

Sample No.	In percent (%)		In gram (g)		Sample Quantity	Material Consumption (g)
	vHDPE	rHDPE	vHDPE	rHDPE		
1	100	0	3000	0	1	3000
2	90	10	2700	300	1	3000
3	80	20	2400	600	1	3000
4	70	30	2100	900	1	3000
5	60	40	1800	1200	1	3000
6	50	50	1500	1500	1	3000
7	40	60	1200	1800	1	3000
8	30	70	900	2100	1	3000
9	20	80	600	2400	1	3000
10	10	90	300	2700	1	3000
11	0	100	0	3000	1	3000
Total material consumptions			**16,500**	**16,500**	**11**	**33,000**

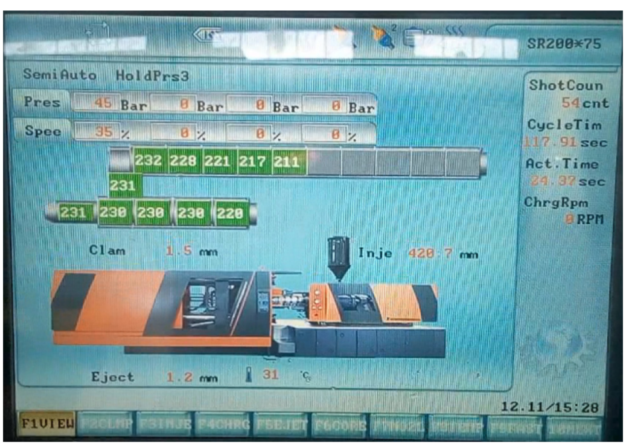

Fig. 5. The input values of machine setup.

Fig. 6. Produced T-Reducer samples.

Finally, the produced samples were all given identification codes which was sticked on the produced as can be seen in Fig. 6.

3. Results and discussion

3.1. Tensile test specimen

ISO 6259–3 according to ISO 527 was used as the standard for the Tensile test for HDPE. At room temperature and constant speed of 50 mm/min, the testing machine was used to produce the dog-bone tensile test specimens as seen in Table 3 and Fig. 7.

All tensile test specimens prepared conformed to the standard as shown in Fig. 8.

3.2. Tensile test results

ISO 6259–3 according to ISO 527 was used as the standard for the Tensile test for HDPE. At room temperature and constant speed of 50 mm/min, the testing machine gave the experimental output readings. Each sample was tested, and three readings were got from each sample, and the final result was the mean of the three readings carried out on each sample. Universal testing machine from Bahir Dar Institute of Technology, Bahir Dar University, Ethiopia and material testing laboratory were used for the testing of the

Table 3
Dimension of test specimen [23].

Symbol	Description	Dimension (mm)
A	Overall length (min.)	150
B	Width of ends	20 ± 0.2
C	Length of narrow, parallel-sided portion	60 ± 0.5
D	Width of narrow, parallel-sided portion	10 ± 0.2
E	Radius	60
F	Gauge length	50 ± 0.5
G	Initial distance between grips	115 ± 0.5
H	Thickness	That of the pipe

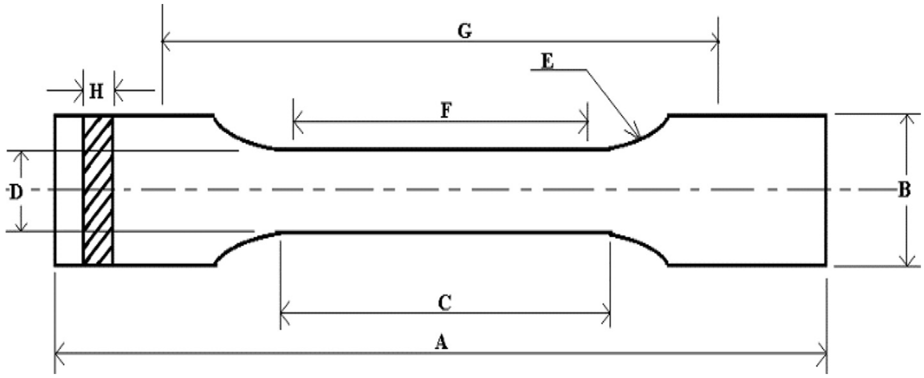

Fig. 7. Tensile test Specimen [23].

Fig. 8. All tensile test specimens.

Table 4
Mechanical Property of vHDPE/rHDPE 100/0.

Sample No	Cross section Area (mm^2)	Maximum load (KN)	Load at brake (KN)	Yield stress (Mpa)	Ultimate Tensile stress (Mpa)	Elongation (mm)	Strain (%)
1	130	2.60	1.77	13.10	19.98	19.28	0.3213
2	130	2.80	1.80	13.06	21.74	23.61	0.3935
3	130	2.64	1.67	11.44	20.31	22.86	0.6600
Average		**2.68**	**1.75**	**12.58**	**20.67**	**21.91**	**0.4583**

samples. The elongation at break values (mm) were taken, tensile strength values (MPa) and Modulus of elasticity (MPa) were also determined. The blend performance of *v*HDPE/*r*HDPE during the tensile tests is seen in Table 4 for the initial ratio of 100/0. In Table 4, ultimate tensile strength, yield strength and elongation and other necessary results can also be seen.

Tests were also carried out on other ratios 90/10, 80/20, 70/30, 60/40, 50/50, 40/60, 30/70, 20//80, 10/90, and 0/100 vHDPE/rHDPE ratio. The summary of all the tests carried out on the other ratios are seen in Table 5 with their average results of tensile strength, tensile strain, tensile stress, applying load, strain and elongation from the virgin HDPE.

Table 5
Comparison of Tensile Strength Results of vHDPE/rHDPE Different Ratios.

Sample No.	Tensile testing results							
	Composition ratio (v:r) in (%)	Max.Load (KN)	Load atBrake (KN)	Tensile stress (MPa)	Yield stress (MPa)	Tensile strain	Elongation (mm)	Change in Tensile strength (%)
1	100:0	2.68	1.75	20.67	12.58	0.32	25.13	0
2	90:10	2.6	1.7	20.03	12.01	0.47	28.01	3.10
3	80:20	2.37	1.53	18.69	11.32	0.52	31.45	9.58
4	70:30	2.35	1.45	18.16	11.04	0.55	33.23	12.14
5	60:40	2.08	1.35	14.83	6.36	0.99	59.59	28.25
6	50:50	1.65	1.02	12.68	5.67	0.65	38.71	38.65
7	40:60	1.48	0.84	11.46	5.43	0.82	49.23	44.55
8	30:70	1.32	0.72	10.19	5.11	0.43	26.29	50.70
9	20:80	1.23	0.64	9.45	5.01	0.58	36.85	54.28
10	10:90	1.16	0.61	8.96	4.56	0.72	39.77	56.65
11	0:100	1	0.6	7.73	4.45	0.16	9.76	62.60

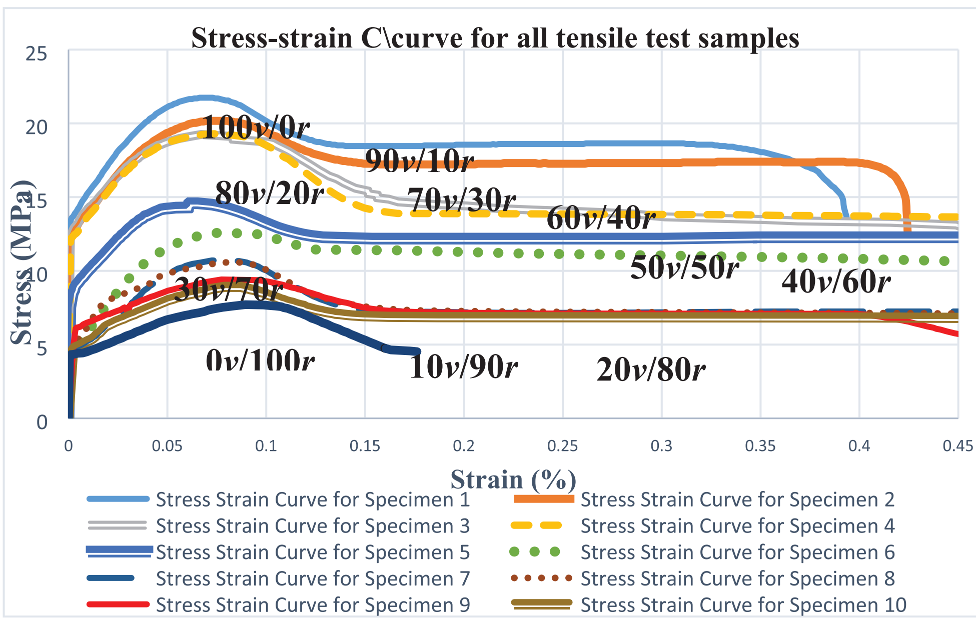

Fig. 9. Stress–strain curve for all tensile test samples.

All the samples stress–strain is seen in Fig. 9 and the differences in the strength behaviour of each sample can be observed in the stress–strain graphs.

At strain of less than 0.2 %, specimens 1, 2 and 4 showed the highest values and with sinusoidal behaviour at close to 0.2% strain. After that, they maintained a steady values between 0.2% and 0.4% strain before showing downward trend. 0v/100r showed the lowest stress out of all the specimens as seen in Fig. 9. The minimum standard requirements were shown by specimens 100v/0r, 90v/10r, 80v/20r, and 70v/30r. While the remaining specimens (60v/40r, 50v/50r, 40v/60r, 30v/60r, 20v/80r, 10v/90r and 0v/100r) couldn't meet the minimum strength requirement. This shows that material strength decreases when there is increase in the recycle ratios beyond 30%. Moreover, tensile strength of the material decreases as the virgin ratio percentage increases as seen in Table 5. Material molecular weight could be responsible for this decrease in strength. Bond strength is very strong in virgin HDPE, and they also have molecular weight that is large. But there is weaker bond strength in 100% recycled scraps of HDPE as a result of different kinds of stresses they have been subjected to during prior usage. Moreover, there is an increase in 100% recycled HDPE water molecules absorption which creates space between bonding. This makes the bond to become very weak and leads to decrease in strength of 100% recycled HDPE. The was decrease in the mechanical property as the ratio of recycle HDPE increases in the composition. Weaker bond strength is exhibited by recycled HDPE as compared to the virgin HDPE. Therefore, increase in ratio has significant effect on the strength of the material.

Good results were shown by 90v/10r. 80v/20r and 70v/30r specimens. Their ultimate tensile strengths were a little bit different from 100v/0r specimen. Other ratios (60v/40r, 50v/50r, 40v/60r, 30v/60r, 20v/80r, 10v/90r and 0v/100r) ultimate tensile strengths were larger as compared to 100v/0r specimen as seen in Table 5. 90v/10r, 80v/20r and 70v/30r specimens showed ultimate tensile strengths of 20.03, 18.69 and 18.16 MPa. After this, there was decrease in the ultimate tensile strengths of the remaining ratios. 100v/0r specimen exhibited 20.67 MPa ultimate tensile strength and difference of 12.14% was shown as compared to 70v/30r specimen. Lowest ultimate tensile strength of 7.73 MPa wa shown by 0v/100r specimen.

3.3. Flexural test

Three-point flexural test universal testing machine from Bahir Dar Institute of Technology, Bahir Dar University, Ethiopia and material testing laboratory were used for the testing of the samples. The experimental procedural is similar to the tensile strength testing earlier mentioned. The only difference is the load application, maximum flexural strength, flexural stress, elongation and flexural strain. At the beam center, vertical bending load was applied, and the test specimen is 20 mm width, 80 mm length and 13 mm thickness. Fig. 10 and Table 6 show the average results of 100v/0r HDPE.

Flexural tests were also carried out on other ratios 90/10, 80/20, 70/30, 60/40, 50/50, 40/60, 30/70, 20//80, 10/90, and 0/100 vHDPE/rHDPE ratio. The summary of all the tests carried out on the other ratios are seen in Tables 7-13 and Figs. 11-16 with their average results of maximum flexural stress, strain, flexural stress, applying load, and elongation.

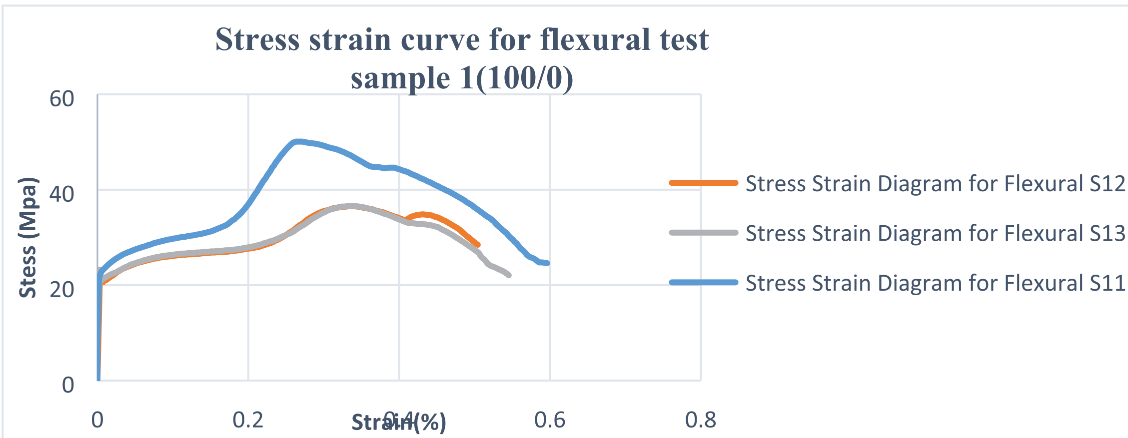

Fig. 10. vHDPE/rHDPE stress–strain curve for 100/0 blends of flexural test (FS1).

Table 6
Flexural Test of vHDPE/rHDPE (100/0).

Sample No	Cross section Area (mm^2)	Maximum load (KN)	Load at brake (KN)	Flexural stress (Mpa)	Max. Flexural stress (Mpa)	Elongation (mm)	Strain (%)
1	260	13.02	6.4	21.23	50.07	35.78	0.596
2	260	9.5	6.78	21.53	36.53	31.34	0.52
3	260	9.52	5.74	23.84	33.34	32.78	0.545
Average		**10.68**	**6.3**	**22.2**	**39.98**	**33.3**	**0.55**

Table 7
Mechanical Property of vHDPE/rHDPE 90/10.

Sample No	Cross section Area (mm^2)	Maximum load (KN)	Load at brake (KN)	Flexural stress (Mpa)	Max. Flexural stress (Mpa)	Elongation (mm)	Strain (%)
1	260	8.36	6.3	20.61	32.15	33.64	0.56
2	260	8.84	6.74	22.15	34	33.87	0.56
3	260	7.52	4.62	16.69	28.92	36.37	0.606
Average		**8.24**	**5.886**	**19.81**	**31.69**	**34.62**	**0.57**

Table 8
Mechanical Property of vHDPE/rHDPE 70/30 Blends.

Sample No	Cross section Area (mm^2)	Maximum load (KN)	Load at brake (KN)	Flexural stress (Mpa)	Max. Flexural stress (Mpa)	Elongation (mm)	Strain (%)
1	260	7.41	6.07	17.07	28.5	32.34	0.54
2	260	7.69	6.29	16.30	29.52	36.11	0.66
3	260	7.84	5.74	18.30	30.15	36.41	0.69
Average		**7.73**	**6.03**	**17.54**	**29.40**	**34.95**	**0.63**

Table 9
Mechanical Property of vHDPE/rHDPE 60/40 Blends.

Sample No	Cross section Area (mm^2)	Maximum load (KN)	Load at brake (KN)	Flexural stress (Mpa)	Max. Flexural stress (Mpa)	Elongation (%)	Strain (%)
1	260	5.9	5	14.07	22.69	35.89	0.63
2	260	6.21	5.4	15.46	23.88	34.61	0.7
3	260	6.58	5.9	17	25.30	33.15	0.69
Average		**6.23**	**5.43**	**15.51**	**23.95**	**34.55**	**0.67**

Table 10
Mechanical Property of vHDPE/rHDPE 50/50 Blends.

Sample No	Cross section Area (mm^2)	Maximum load (KN)	Load at brake (KN)	Flexural stress (Mpa)	Max. Flexural stress (Mpa)	Elongation (mm)	Strain (%)
1	260	6.65	6.07	11.73	25.57	36.51	0.60
2	260	5.81	5.25	11.07	22.34	37.37	0.62
3	260	5.89	5.61	12.15	22.65	34.2	0.57
Average		**6.11**	**5.64**	**11.93**	**23.52**	**36.02**	**0.59**

Table 11
Mechanical Property of vHDPE/rHDPE 10/90 Blends.

Sample No	Cross section Area (mm^2)	Maximum load (KN)	Load at brake (KN)	Flexural stress (Mpa)	Max. Flexural stress (Mpa)	Elongation (mm)	Strain (%)
1	260	5.72	4.18	8.69	22	38.45	0.64
2	260	5.74	4.2	9.46	22.07	37.39	0.62
3	260	5.78	4.38	8.07	22.23	36.88	0.61
Average		**5.74**	**4.25**	**8.74**	**22.1**	**37.57**	**0.62**

Table 12
Mechanical Property of vHDPE/rHDPE 100/0 Blends.

Sample No	Cross section Area (mm^2)	Maximum load (KN)	Load at brake (KN)	Flexural stress (Mpa)	Max. Flexural stress (Mpa)	Elongation (mm)	Strain (%)
1	260	5.99	5.21	7.69	23.03	36.99	0.61
2	260	5.53	5.11	7.8	21.26	35.6	0.59
3	260	5.43	5.03	7.69	20.88	37.7	0.62
Average		**5.65**	**5.11**	**7.72**	**21.72**	**36.76**	**0.6**

Table 13
Comparison of Flexural Strength Results of vHDPE/rHDPE Different Ratios.

Sample No.	Flexural testing results							
	Ratio (v:r) in (%)	MaxLoad (N)	Load at Brake (N)	Max. Flexural stress (MPa)	Flexural stress (MPa)	Flexural strain (%)	Elongation (mm)	Change in Flexural strength (%)
1	100:0	10.68	6.3	41.07	22.2	0.55	33.3	0
2	90:10	8.24	5.88	31.69	19.81	0.57	34.62	13.16
3	80:20	7.81	6.32	30.04	17.91	0.55	33.27	24.86
4	70:30	7.73	6.03	29.40	17.54	0.63	34.95	26.46
5	60:40	6.23	5.43	23.95	15.51	0.67	34.55	47.75
6	50:50	6.11	5.64	23.52	11.93	0.59	36.02	41.17
7	40:60	5.49	5.68	21.12	11.02	0.62	37.66	47.17
8	30:70	5.94	4.7	22.85	10.15	0.57	34.76	42.85
9	20:80	5.75	4.59	22.12	9.71	0.62	37.64	44.67
10	10:90	5.74	4.25	22.1	8.74	0.62	37.57	44.72
11	0:100	5.65	5.11	21.72	7.72	0.6	36.76	45.67

The summary of the flexural tests was carried out on other ratios 90/10, 80/20, 70/30, 60/40, 50/50, 40/60, 30/70, 20//80, 10/90, and 0/100 vHDPE/rHDPE ratio. The summary of all the tests carried out on the other ratios are seen in Tables 13 with their average results of maximum flexural stress, strain, flexural stress, applying load, young modulus, and elongation.

The flexural strength of the material decreases (22.20 to 7.72 MPa) as the virgin ratio percentage increases as seen in Table 13. Material molecular weight could be responsible for this decrease in strength. Bond strength is very strong in virgin HDPE, and they also have molecular weight that is large. Also, there is highest rigidity in virgin HDPE. Rigidity is very high in virgin HDPE due to high toughness. So, with lower load, bond strength is not allowed to break. But there is weaker bond strength in 100% recycled scraps of HDPE as a result of different kinds of stresses they have been subjected to during prior usage. In addendum, there is an increase in 100% recycled HDPE water molecules absorption which creates space between bonding. This makes the bond to become very weak and leads to decrease in flexural strength of 100% recycled HDPE. There was decrease in the mechanical property as the ratio of recycle HDPE increases in the composition. Weaker bond strength is exhibited by recycled HDPE as compared to the virgin HDPE. Therefore, increase in ratio has significant effect on the flexural strength of the material as seen in Table 13. There was decrease in all the mechanical properties (flexural and tensile) as seen in Tables 5 and 13, as a result of increase in recycled HDPE.

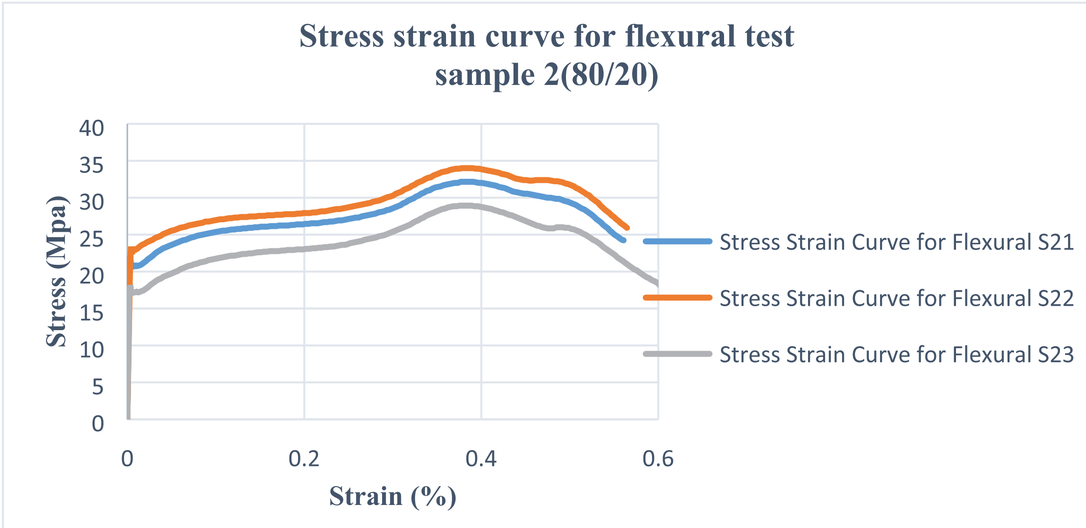

Fig. 11. vHDPE/rHDPE stress–strain curve for 10/90 blends of flexural test (FS2).

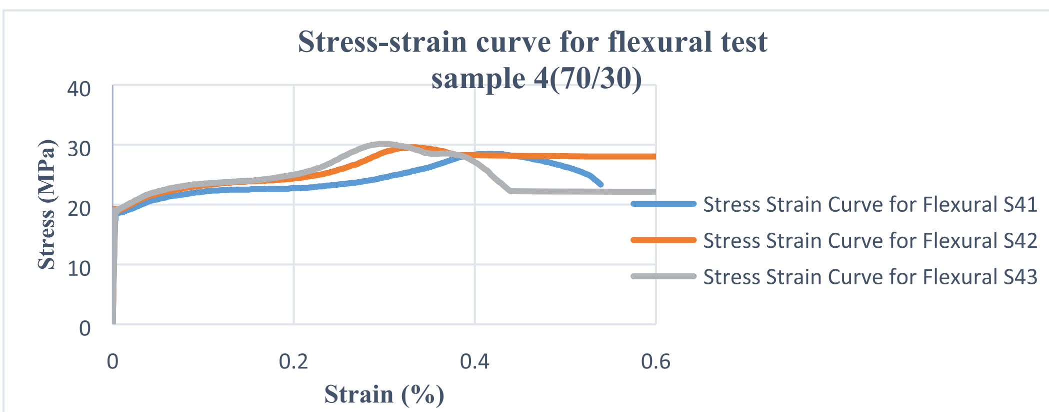

Fig. 12. vHDPE/rHDPE stress–strain curve for 70/30 blends of flexural test (FS4).

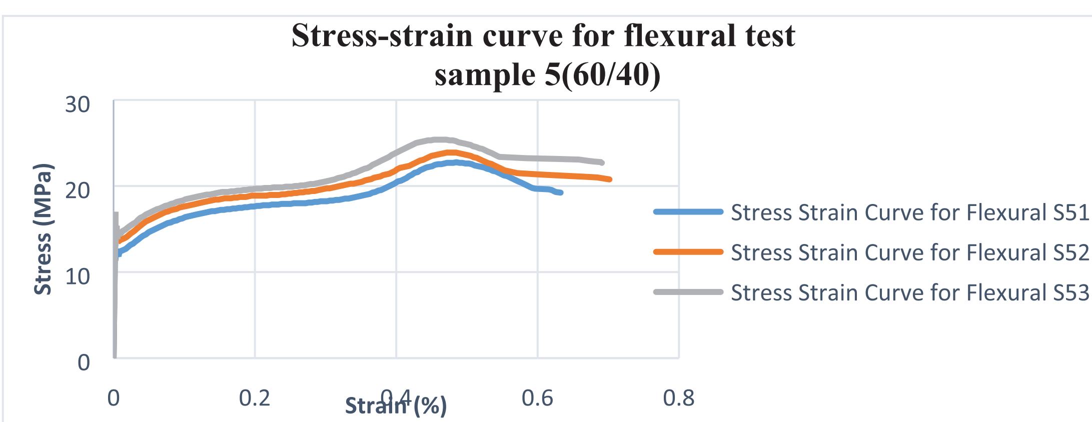

Fig. 13. vHDPE/rHDPE stress–strain curve for 60/40 blends of flexural test (FS5).

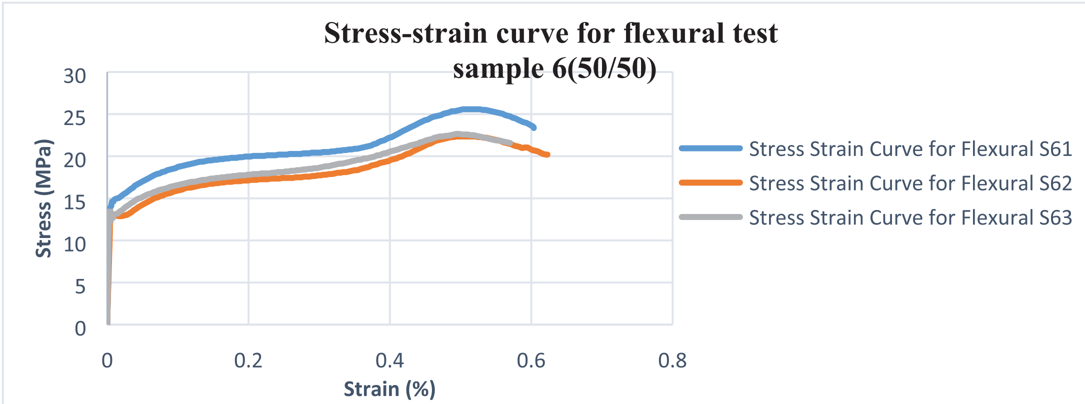

Fig. 14. vHDPE/rHDPE stress–strain curve for 50/50 blends of flexural test (FS6).

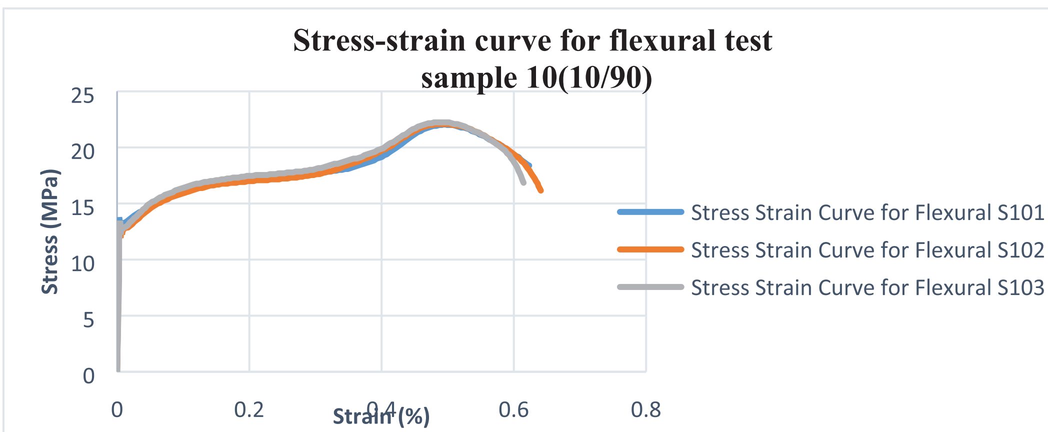

Fig. 15. vHDPE/rHDPE stress–strain curve for 10/90 blends of flexural test (FS10).

4. Conclusion

- The experimental analysis shows that it is possible to use recycled high-density polyethylene (rHDPE) scraps for pipe fitting production application up to 30 wt%. Tensile and flexural strengths results indicate that addition up to 30 wt% scrap meet the standard requirement.
- Bond strength is very strong in virgin HDPE, and they also have molecular weight that is large. Also, there is highest rigidity in virgin HDPE. Rigidity is very high in virgin HDPE due to high toughness. So, with lower load, bond strength is not allowed to break. But there is weaker bond strength in 100% recycled scraps of HDPE as a result of different kinds of stresses they have been subjected to during prior usage
- Increase in ratio of recycled HDPE has significant effect on the flexural strength of the material. There was decrease in all the mechanical properties (flexural and tensile) as a result of increase in recycled HDPE.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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