Recycling of Commingled Plastics Waste Containing Polyvinylchloride, Polypropylene, Polyethylene and Paper

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ABSTRACT

In this article various blends of polyvinylchloride (PVC), polypropylene (PP) and high-density polyethylene (HDPE) were prepared. Mechanical properties and morphology of the samples were investigated. Then hydrolyzed paper was added and for improvement of impact strength of the blends about 10 wt% ethylene-propylene-diene copolymer (EPDM) was used. The results show that EPDM improves the impact strength of the blends. The mechanical properties and morphology of various blends of PP/HDPE/PVC/EPDM/paper with 2 wt% calcium stearate (CS) were studied. We concluded that compositions 4.8/43.2/10/10/30 and 38.4/9.6/10/10/30 (w/w) had better impact strength than other blends. The blends with waste materials were also prepared by the same ratios. They also showed better impact strength than PP/HDPE blends. These blends can be used as artificial wood.

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Key Words:
recycling;
plastics waste;
polymer blend;
paper;
commingled plastics.

INTRODUCTION

A substantial part of municipal solid waste (MSW) streams is composed of mixed polymers. High-density polyethylene (HDPE), polypropylene (PP) and polyvinyl chloride are among the most common plastics waste, since they are the most frequently used commercial plastics in our daily lives as well as in industries [1].

A number of approaches are currently being investigated for dealing with post consumer resin.

Incineration for the purpose of

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waste-to-energy recovery is used in a number of countries, which are feard of pollution. Another solution that is currently being developed is pyrolysis. A number of companies are now introducing low levels of plastics waste into hydrocrackers that produce Naphtha, which can then be used as part of feedstock for other applications, including polymerization. A popular solution is the reuse of plastic parts, such as PET drinking bottles in Europe.

Lastly, there is the approach of converting municipal plastics waste into resins, which can be used to make new articles.

The mixed plastics waste can be recycled in the form of blends [2-5]. The processing of plastics mixtures for recycling has been attempted with some success [6-11]. But the plastics fraction obtained by sorting municipal solid wastes often contains substantial quantity of paper. The reprocessing of such material is very difficult even at paper levels as low as 10% [12], beside this, the product's appearance is unacceptable due to the inhomogeneity of the mixture, and the mechanical properties are unsatisfactory [13].

Recently, some methods were used to treat paper and produce a form that could be added for recycling the mixture. Klason et al. [14,15] reported a HCOOH treatment hydrolyzing in gas phase for this purpose. As our previous work, HCl can be used for hydrolysis of paper. Since Iran Petrochemical Co. produces HCl in large scale and regarding the local economical aspects we focused on a treatment based on HCl [16].

In this study polyvinylchloride (PVC) is added to the blends of PP/HDPE/EPDM/paper and PP/HDPE, (because usually PVC contributes a part of MSW) and the morphology and mechanical properties of the blends were investigated. First, we focus on the virgin materials and then continue with waste materials. The final products can be used as artificial wood.

EXPERIMENTAL

Materials

High density polyethylene (HDPE GF 4760, MFI = 21 g/10 min, d = 0.954 g/mL), and polypropylene (PP X30S, MFI = 9 g/10 min, d = 0.9 g/mL) were products of Arak Petrochemical Co., Iran. Polyvinylchloride (contains stabilizers) with 34% DOP was obtained from Granule Ghazvin Co., Iran, home-made calcium stearate (CS) and EPDM (Vistaloon 7500) were used as received.

Testing

The samples were prepared for testing by melt-mixing process in a Haake Rheomix 750 internal mixer. The mixing time, rotation speed and temperature were 7 min, 40 rpm and 165 C, respectively. The compression moulding technique was used for preparation of testing bars. Tensile testing was performed on an Instron 6025 tensile testing machine, according to ASTM D638. The cross-head speed was 50 mm/min and the dimensions of the samples were 75 x 5 x 0.8 mm. Izod impact property was determined using a Zwick 5102 impact tester according to ASTM D256. Samples for the Izod impact strength measurements had the dimensions of 63 x 12.5 x 3 mm. The results were obtained from at least 5 test samples. To observe the morphology of the various blends, compression moulded samples were fractured under liquid nitrogen and then fracture surface of the samples sputtered with gold in vacuum. These samples were examined by a scanning electron microscope (SEM), Cambridge S360.

Sample Preparation

In our previous paper [16] we reported on the effect of addition of hydrolyzed paper to high-density polyethylene and polypropylene (HDPE/PP) blends and we concluded that about 30% (w/w) hydrolyzed paper could be added to the optimum blends. For paper hydrolysis, three inorganic and organic acids, HCl, H_2SO_4 and HCOOH with different concentrations were prepared. The results showed that HCl would be the best choice [16].

The blends of PP/ HDPE with the ratio 10/90 and 80/20(w/w) have the best mechanical properties (80/20 has better modulus and tensile strength and 10/90 has better impact strength than other blends), so we called them optimized blends and they were used in the continuing work. Then 30 wt% of the hydrolyzed paper was added to the optimum blends and for improving the impact resistance of these blends, about 10 wt% ethylene/propylene/diene copolymer (EPDM) was added.

Then about 5 and 10% (w/w) polyvinylchloride (PVC) was added to the optimum blends of PP/HDPE/EPDM/paper and PP/HDPE, (because usually PVC contributes a part of MSW) and the morphology and mechanical properties of the blends were investigated.

RESULTS AND DISCUSSION

First of all, we prepared various blends of PP/HDPE, PP/HDPE/hydrolyzed paper and PP/HDPE/EPDM/

Table 1. The composition and mechanical properties of various blends[16].

PP/PE (weight percent)	Tensile strength (MPa)	Impact strength (J/m)	Modulus (MPa)	Elongation at break (%)
0/100	15	389	650	120
10/90	16	94	700	45
20/80	18	20	800	11
40/60	23	21	850	7.5
60/40	24	12	1000	4.5
70/30	26	15	1010	7
80/20	27	35	1050	11
100/0	30	22	1200	13

hydrolyzed paper (paper hydrolyzed by HCl/ water solution in a definite concentration) [16]. Table 1 shows the composition of various blends of PP/HDPE and their mechanical properties. By adding paper (up to 30%) to PP/PE (80/20 and 10/90) blends, the presence of cellulose fibre increases the tensile strength and modulus of the PP/HDPE/paper composites, but impact strength is decreased. Because in this case, paper acts as filler and reduces the consistency of the matrix, therefore, it decreases the mechanical properties (Table 2).

The SEM micrographs of various PP/HDPE blends (10/90,80/20,70/30) confirmed the interfacial adhesion, so that the compatibility of phases and mixing in the 10/90 and 80/20 blends are better than the other compositions, such as 70/30 blend [16].

For improving the impact strength of 80/20 and 10/90 PP/HDPE blends with 30% (w/w) paper, EPDM (10% w/w) was added. Table 2 shows the mechanical properties and compositions of these blends [16].

Table 2. The mechanical properties of PP/HDPE/paper/EPDM blends.

No.	PP/HDPE/paper/EPDM (w/w)	Tensile strength (MPa)	Impact strength (J/m)
1	56/14/30/0	28	19
2	7/63/30/0	17.6	59
3	48/12/30/10	17	30
4	6/54/30/10	16.5	90

Compositions number 1 and 2 contain PP/HDPE/paper.

Chang-Sik et al. reported that the addition of a compatibilizer into a binary blend enhances the mechanical properties such as impact strength [17].

For preparing the ternary blends of PP/HDPE/PVC, calcium stearate 2 wt% was added to the mixtures as a lubricant. Table 3 shows the compositions and mechanical properties of these blends. PVC Content of the blends is 5 and 10 wt%, because the PVC in the municipal plastic waste streams of Iran is not more than 10 wt%. In the Tables 3-5 the ratio of PP/HDPE is 10/90 (in blends 1 and 3) and 80/20 (in blends 2 and 4).

Table 4 shows the composition and the mechanical properties of various blends of PP/HDPE/PVC/EPDM (with calcium stearate). It shows tensile strength of the blends is decreased but the impact strength is increased. In this case EPDM acts as an impact modifier and increases the impact strength of the blends. It was reported that the addition of a compatibilizer into a binary blend enhances the mechanical properties, such as impact strength, because of the additive located at the interface between the phases. It enhances the stress transfer and reduces particle size because of the emulsifying effect [6,17-19].

It has been reported that EPDM works as effective

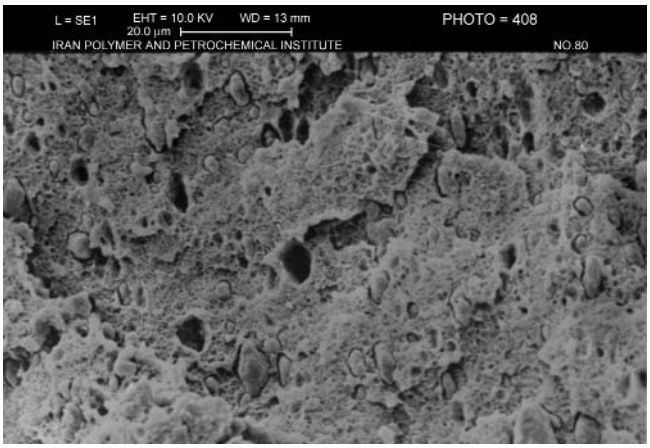

Figure 1. SEM Micrograph of PP/HDPE/PVC:8.8/79.2/10 (w/w) blend with 2 wt% (CS).

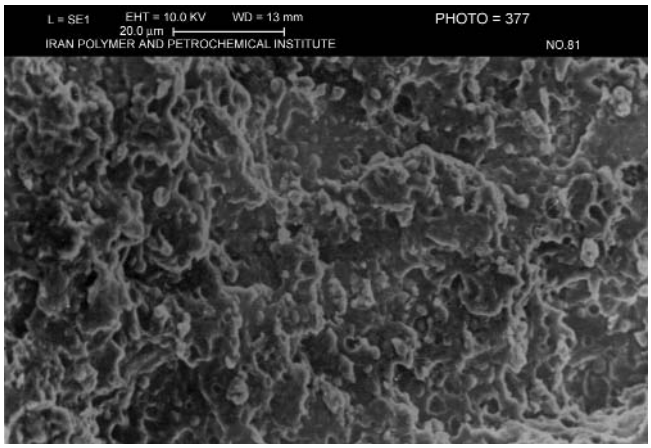

Figure 2. SEM Micrograph of PP/HDPE/PVC:70.4/17.6/10 (w/w) blend with 2 wt% (CS).

Table 3. The compositions and mechanical properties of PP/HDPE/PVC blends.

No.	PP/HDPE/PVC with (CS) (w/w)	Tensile strength (MPa)	Impact strength (J/m)
1	9.3/83.7/5/2	15	144
2	74.4/18.6/5/2	25	37
3	8.8/79.2/10/2	14	152
4	70.4/17.6/10/2	24.5	42
5	0/0/100	20	No break

The ratio of PP/HDPE is 10/90 in blends 1 and 3, 80/20 in blends 2 and 4.

impact modifier for the ternary blend of HDPE/PP/PVC. The result is thought to be attributable to the strong interaction of EPDM to HDPE and PP to increase interfacial adhesion between them [6]. As expected, the impact strength of the blends is enhanced when EPDM is added.

The SEM micrographs of PP/HDPE/PVC (with 2 % w/w CS) blends with the ratio of 8.8/79.2/10/2 (PP/ HDPE: 10/90) and 70.4/17.6/10/2 (w/w) (PP/ HDPE: 80/ 20) are shown in Figures 1 and 2, respectively. Figures 3 and 4 show these blends with 10 wt% EPDM. As Figures 1 and 2 show the minor polymer particles are dispersed in the matrix (major polymer phase) and the particles can be seen, but in Figures 3 and 4 by addition of EPDM, the dispersed domain size of compatibilized system become much smaller with more compact structure than uncompatibilized samples. This phenomenon is confirmed, however, by mechanical properties.

Table 5 shows the compositions and mechanical properties of PP/HDPE/PVC/EPDM /paper blends. The impact strength is decreased (compared with Table 4),

Table 4. The compositions and mechanical properties of PP/HDPE/PVC/EPDM blends.

No.	PP/HDPE/PVC/EPDM with (CS) (w/w)	Tensile strength (MPa)	Impact strength (J/m)
1	8.3/74.7/5/10/2	14	No Break
2	66.4/16.6/5/10/2	19	40
3	7.8/70.2/10/10/2	6	No Break
4	62.4 /15.6/10/10/2	13	49

The ratio of PP/HDPE is 10/90 in blends 1 and 3, 80/20 in blends 2 and 4.

but they are still higher than the values for the binary blends of PP/HDPE or the other blends in the Table 2 (comparing items 3 and 4 in Table 5 with items 3 and 2 in Table 2). The tensile strength is increased, because by hydrolyzation, the paper is converted to the high modulus cellulose fibres. The addition of PVC and EPDM overcame the effect of hydrolyzed paper on decreasing the impact strength and increases this property. Since the end use of these blends as artificial wood, the improvement of impact strength is more important than the decreasing of the other properties.

Figures 5 and 6 show the SEM micrographs of PP/HDPE/PVC/EPDM/paper with the ratio of 4.8/43.2/10/10/30 (PP/HDPE:10/90) and 38.4/9.6/10/10/30 (PP/HDPE:80/20) (wt%), respectively. In Figure 6 the dispersed phase domain is smaller in size than the dispersed phase in Figure 5 and it shows that the blends with the ratio of 38.4/9.6/10/10/30 (PP/HDPE:80/20) has better compatibility in comparison with the blend with the ratio of 4.8/43.2/10/10/30 (PP/HDPE:10/90). Because in 4.8/43.2/10/10/30 blend the predominant phase is HDPE, the impact strength of this blend is more than 38.4/9.6/10/10/30 blend. The mechanical

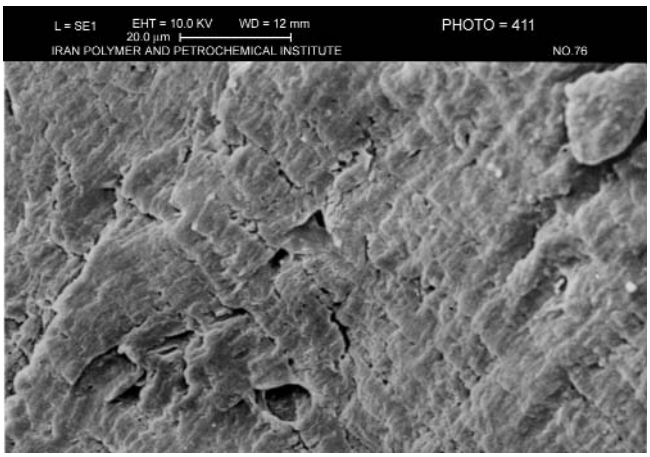

Figure 3. SEM Micrograph of PP/HDPE/PVC/EPDM: 7.8/70.2/10/10 (w/w) blend with 2 wt% (CS).

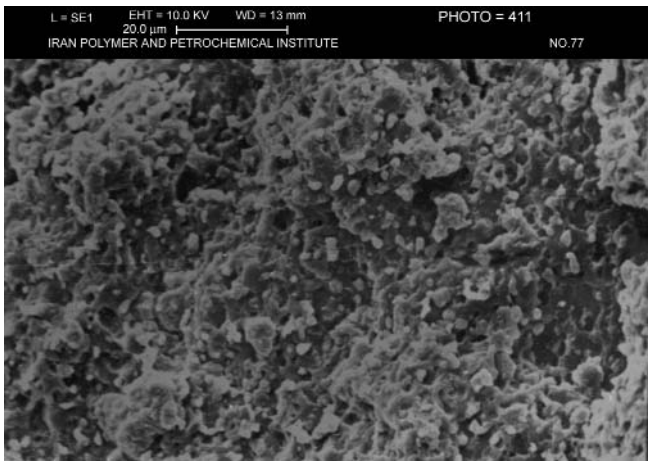

Figure 4. SEM Micrograph of PP/HDPE/PVC/EPDM: 62.4/15.6/10/10 (w/w) blend with 2 wt% (CS).

Table 5. The compositions and mechanical properties of PP/HDPE/PVC/EPDM/paper blends.

No.	PP/HDPE/PVC/EPDM/paper with (CS) (weight percent)	Tensile strength (MPa)	Impact strength (J/m)
1	5.3/47.7/5/10/30/2	15	123
2	42.4/10.6/5/10/30/2	20	35
3	4.8/43.2/10/10/30/2	8.5	112
4	38.4/9.6/10/10/30/2	15	38

The ratio of PP/HDPE is 10/90 in blends 1 and 3, 80/20 in blends 2 and 4.

properties confirm these results.

Regarding the formulation (PP/HDPE/PVC/EPDM/paper) there are two main groups of blends, as follows:

(I). HDPE is a predominant phase, with the ratio of the components 4.8/43.2/10/10/30 (w/w) (PP/HDPE: 10/90).

(II). PP is the predominant phase, with the ratio of the components: 38.4/9.6/10/10/30 (w/w) (PP/HDPE: 80/20).

Then we have collected plastics waste and paper from a stream of municipal solid waste for 3 months. The plastics portion of it contains various bottles of milk, detergents, vegetable oil, bags, etc. and most of them were polyethylene and up to 10 wt% PP and less than 10 wt% PVC. The waste stream had about 10 wt% paper which was used as label on the containers, so we added about 20 wt% waste paper to the mixture.

After grinding, cleaning and washing, the paper was hydrolyzed. Then the mixture of the plastics with paper and about 10 wt% EPDM and CS (2 wt%) was

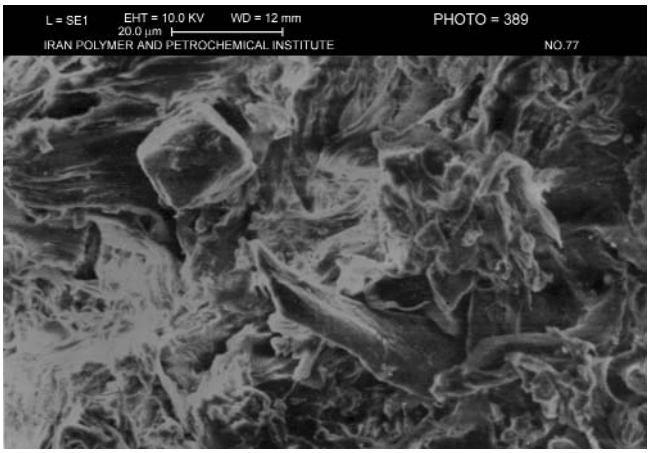

Figure 5. SEM Micrograph of PP/HDPE/PVC/EPDM/paper: 4.8/43.2/10/10/30 (w/w) blend with 2wt% (CS).

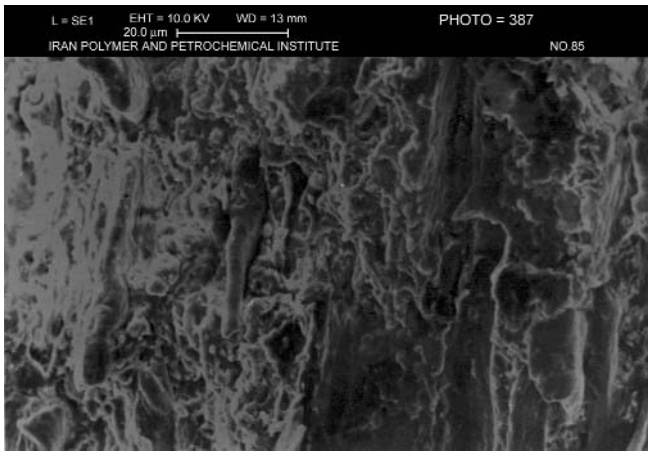

Figure 6. SEM Micrograph of PP/HDPE/PVC/EPDM/paper: 38.4/9.6/10/10/30 blends with 2wt%(CS).

mixed in an internal mixer and the mechanical properties of these blends were investigated. Figure 7 shows the comparison of the tensile strength of binary blend of PP/HDPE (10/90), ternary blend of PP/HDPE/PVC, PP/HDPE/PVC/EPDM/paper (blank) blend and recycled blend. As it shows the tensile strength of the recycled blend is a little less than the blank blend and less than the PP/HDPE blend. But in Figure 8 it can be seen that the impact strength of the recycled sample is higher than the binary blend. As these recycled blends finally will be used as artificial wood, the improvement of impact strength is more important than the decreasing of tensile strength.

As the result of a separate experiment, the impact strength of maple wood was 400 J/m. Wood has higher impact strength in comparison with human-made composites,

So, the impact strength of our product (which is about 110 J/m) could be acceptable for use as artificial wood.

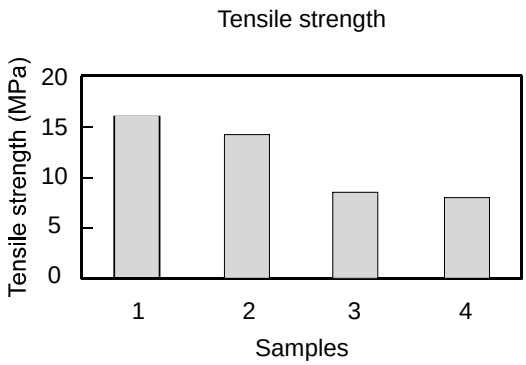

Figure 7. The comparison of tensile strength of (1): binary blend of PP/HDPE, (2): ternary blend of PP/HDPE/PVC, (3): blank sample, (4): recycled sample.

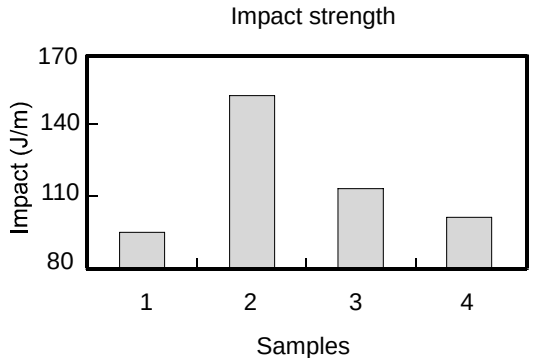

Figure 8. The comparison of impact strength of (1): binary blend of PP/HDPE, (2): ternary blend of PP/HDPE/PVC, (3): blank sample, (4): recycled sample.

CONCLUSION

Hydrolysis treatment of paper improves the homogeneity and the mechanical properties of the PP/HDPE/PVC/paper composites.

The PP/HDPE/PVC/EPDM/paper blends with the ratio of 4.8/43.2/10/10/30 (w/w) (PP/HDPE:10/90) and 38.4/9.6/10/10/30 (w/w) (PP/HDPE:80/20) with 2 wt% calcium stearate have good impact strength in comparison with binary blends of PP/HDPE or PP/HDPE/paper blends. So, we can modify the composition of the sorting plastics waste mixture with the paper to these ratios and then add about 10 wt% EPDM to the mixtures for improving the impact property of these blends. The final product has acceptable specifications to be used as artificial wood.

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