Impact strength and surface hardness properties: virgin PVC versus recycled PVC composites filled with two different natural fibers

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ABSTRACT

This study compares the impact strength and hardness properties between virgin polyvinyl chloride (vPVC) and recycled polyvinyl chloride (rPVC) composites filled with two different natural fibers (palm fibers and sawdust). Composites with fiber content varied from 2 to 8 wt% were prepared successfully using mini-extruder. The effects of the fiber type and fiber content were studied. As expected, the fiber type and fiber content played an important role in the investigated properties of PVC composites. The results raveled that the incorporation of palm fiber and sawdust into vPVC matrix showed to decrease the impact strength. Opposite effect was observed when palm fiber and sawdust were incorporated into rPVC matrix. The results of hardness pointed out that the average surface hardness values of rPVC and their composites were higher than that of vPVC and their composites. Sawdust-PVC composites (with either vPVC or rPVC) showed to have better impact strength and slightly higher surface hardness values than those of palm fibers-PVC composites.

Keywords: : polyvinyl chloride, recycled polyvinyl chloride, palm fiber, sawdust, impact strength

1. Introduction

Polyvinyl Chloride (PVC) is one of the most widely produced and used polymers in the world due to its versatile nature. PVC is a general purpose plastic and has different features in terms of performance and function, valuable properties, wide range of applications, high chemical resistance, barrier properties and low cost. PVC is used in a variety of applications in the construction, health care, electronics, automobile, packaging and other sectors, in products ranging from piping and siding, blood bags and tubing, to wire and cable insulation, windshield system components and more. On the contrary, processibility and thermal stability of PVC is known to be inferior compared with common polymers [1]. Moreover, PVC has been described as one of the most hazardous waste ever created [2]. Problems of PVC waste can be solved via recycling, while its weak properties can be enhanced by compounding PVC with a number of additives. The most useful additives in PVC are plasticizers, heat stabilizers, lubricants, fillers, and pigments [3].

Natural fibers (NFs) are the one of popular additive that uses as filler or reinforcement in PVC matrix to produce PVC-NF composites. NFs play an important role in developing high performance biodegradable composites which are the key material in solving nowadays environmental and 3R (Recycle-Reuse-Reduce) issues, due to its low cost, low density, renewability, biodegradability, less damage to processing equipment and minimal health hazards [4-7]. Many different NFs have been utilized to reinforce polymer matrix composites. NFs can be obtained from plant such as oil palm, bagasse, corn stalks, coir, bamboo, pineapple, banana as well as rice husk which extracted on their part of plant (stem, leaf, seed, fruit, stalk and grass/reed) [8]. Singha and Thakur [9] stated that the properties of NFs can vary depending on the source, age and separating techniques of the fibers. Gowda et al. [10] stated that due to its compactibility with the natural fibers, less cost, durability, chemical and flame resistance, PVC has become more appropriate material to build structures and in other construction works.

PVC-NF composites are gaining favor because they can offer acceptable mechanical properties, rot roof ability, chemical and moisture resistance, as well as long lifetime. According to Yotkaew et al. [11], PVC-NF composite products has been increased at the present because of many benefits, such as cost reduction, dimension stability, versatile properties, recycling purposes, and environmentally friendly. They are most often used in building construction applications, such as window/door profiles, decking, railing, and siding, representing about 22% of the marketing [12]. However, PVC composites have the wide range of application and their use has grown more rapidly than of other polymer composites [13].

In this study, comparison in the impact strength and surface hardness properties between vPVC and rPVC composites filled with two different natural fibers with variation of fiber type and content were accomplished. Reliable strength and hardness evaluations help to get idea on the overall mechanical properties of a material. Impact test is used to determine the amount of impact energy that was required to break the specimen. Impact strength of a composite is the ability of the material to resist the fracture failure under sudden applied at high speed and is interrelated to the toughness [14]. On the other hand, hardness can be counted as a measure of the plastic deformation that the material can suffer under the influence of external stress [15]. Hardness is a composite property including in some way tensile strength, proportional limit, ductility, work hardening properties, shear strength, modulus of elasticity, wear and other properties [16-17].

2. Materials and Methods

2.1 Materials and Treatment

The materials used in this study were virgin PVC, PVC waste, palm fibers and sawdust. Virgin PVC was donated by local companies. PVC waste was collected from domestic waste. PVC waste was cleaned properly and chopped for the preparation of composites. Palm fiber was collected from agricultural farm areas (Zliten - Libya) and dried in sunlight to lower the moisture level. Subsequently, palm fiber was sieved to remove the impurities and passed through different sieves size to get particle size of (< 75) μm. Sawdust was collected from local furniture factories. Sawdust was dried and sieved similar to palm fiber.

2.2 Composite Preparation

About sixteen composites were papered. The desire amount of PVC (virgin and waste) was mixed with different palm fiber load using rotor ultra centrifugal mill ZM 200. The final mixing was carried out using Haake miniCTW twin screw with average screw speed of (60 r.p.m.) and barrel temperatures of 180 ^{o}C. The extruded materials were cooled in air and then granules to small pieces. Likewise, composites with sawdust were prepared. All specimens for impact strength and shore hardness were prepared using injection molding (Xplore 12ml). Details of the composites and codes are reported in Table 1.

Table 1. Composites composition and codes

Nº	Composite code	Virgin PVC, wt.%	Waste PVC, wt. %	Palm fiber, wt.%	Sawdust wt.%
1.	vPVC	100	0.0	0.0	0.0
2.	vPVCP1	98	0.0	2	0.0
3.	vPVCP2	96	0.0	4	0.0
4.	vPVCP3	94	0.0	6	0.0
5.	vPVCP4	92	0.0	8	0.0
6.	rPVC	0.0	100	0.0	0.0
7.	rPVCP1	0.0	98	2	0.0
8.	rPVCP2	0.0	96	4	0.0
9.	rPVCP3	0.0	94	6	0.0
10.	rPVCP4	0.0	92	8	0.0
11.	vPVCS1	98	0.0	0.0	2
12.	vPVCS2	96	0.0	0.0	4
13.	vPVCS3	94	0.0	0.0	6
14.	vPVCS4	92	0.0	0.0	8
15.	rPVCS1	0.0	98	0.0	2
16.	rPVCS2	0.0	96	0.0	4
17.	rPVCS3	0.0	94	0.0	6
18.	rPVCS4	0.0	92	0.0	8

2.3 Characterization

2.3.1Charpy impact testing

The charpy impact test was carried out to determine the impact strength of the vPVC, rPVC, and their composites using CEAST Resil Impactor tester, with impact energy of 15 J. The specimens of impact test were notched according to ASTM (D256-87). All the specimens of impact test of raw PVC, PVC waste and composites were standard of (thickness 4mm, width 10mm and length 100 mm). Average of minimum three specimens was tested for vPVC, rPVC and each composite.

2.3.2 Shore hardness

The hardness of molded vPVC, rPVC and their composites was determined using a Shore D durometer (RayRan) in accordance with ISO 868:2003. Shore D hardness technique measures the depth of penetration of an indenter. Hardness value for each sample is an average of eight measurements.

3. Results and Discussion

Figure 1, shows the impact strength of vPVC and their composites versus fiber content. As can be seen in Figure 1, the fiber type and fiber content play an important role in impact strength properties of composite materials. The incorporation of palm fiber and sawdust in the vPVC matrix showed to decrease the impact strength. Reports in the literature indicate that impact resistance often decreases as an effect of wood reinforcement [18-21]. The decrease of impact strength of composites was resulted from the poor interfacial adhesion between fibers and vPVC matrix. The poor interfacial bonding between polymer matrix and fibers resulted in poor impact property of composites [22].

All composites show with vPVC, regardless of the employed type of fiber, a comparable behavior (parabola shape) and maximum impact strength at the same fiber content 8 wt%. In all composites with vPVC, the impact strength showed to decrease with increasing the fiber up to 4 wt%, then started to increase. The minimum impact strength was observed at 4 wt% fiber content. Increasing the fiber content in the composite materials will increase the impact strength [23-24]. Salman et al. [25] stated that fiber content played an important role in the interfacial bonding between kenaf fiber and PVB film, which affects the mechanical properties of the composite. However, impact strength of sawdust composites was slightly higher than palm fiber composites. This could be due to nature of the fibers [26]. Generally, impact strength properties of composite materials are mainly influenced by several factors such as the percentage of fiber, fiber properties, fiber content, matrix properties, and fiber and matrix interface properties, especially when combining natural fibers with thermoplastics [27-29].

Figure 1. Effect of fiber type and fiber content on impact strength of vPVC composites.

Figure 2, shows the impact strength of rPVC and their composites versus fiber content. The impact strength properties of rPVC composites were noticeably different from vPVC composites. Conversely, the incorporation of palm fiber and sawdust in the rPVC matrix showed to increase the impact strength. This is because different rPVC products are expected to have different formulations of additives such as calcium carbonate, lubricants, stabilizers and impact modifiers. Furthermore, they may have different particle dimensions and different apparent density, dependent on the grinding process undergone before processing [30]. It is important to know that even by separate collection of PVC wastes by type of product it is hardly possible to gain PVC material of an exactly uniform composition [31]. In both composites with rPVC, the impact strength was increased with addition of 2 wt% of fiber and then they started to decrease. This indicates that the maximum impact strength of composites made with rPVC was observed at 2 wt% fiber content. Moreover, as in the case of vPVC composites, composites of rPVC with sawdust exhibited higher impact strength values in comparison to composites of rPVC with palm fibers. Sawdust fiber is a good representative of abundant natural fiber containing high percentage of cellulose [32].

Figure 2. Effect of fiber type and fiber content on impact strength of rPVC composites.

The influence of matrix type on the impact strength of the composites with different fiber content is shown in Figure 3. It is interesting to note that the impact strength of rPVC and their composites were remarkably higher that of vPVC and their composites. Many studies [33-34] have found that the impact properties or shock resistance of products contained rPVC were comparable or even better than those of vPVC. Moreover, PVC (either rPVC or vPVC) composites with sawdust were exhibited higher impact properties than those with palm fiber.

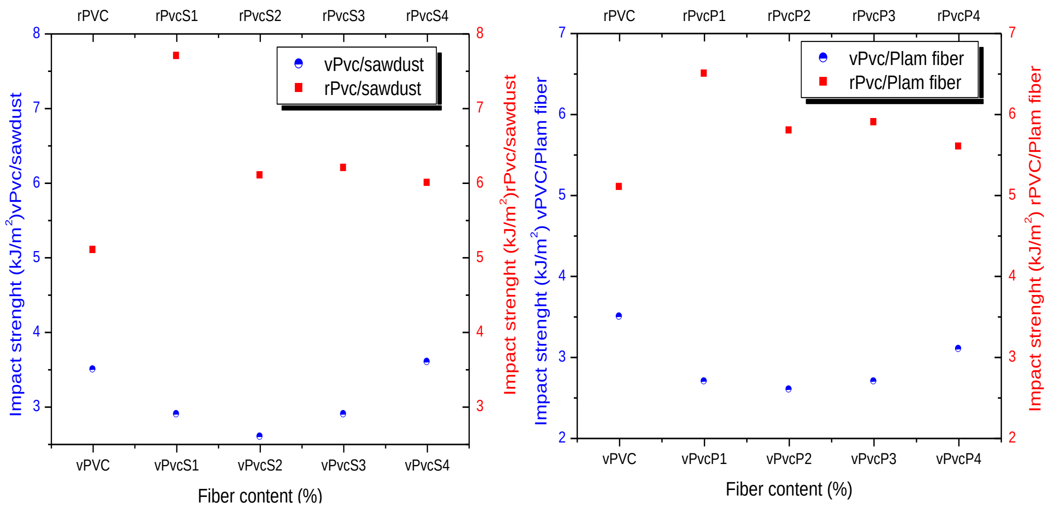

Figure 3. Influence of matrix type on the impact strength.

In impact test, the sample will absorb energy until it yields. At this point, the sample will begin to undergo plastic deformation at the notch. The test sample continues to absorb energy and work hardens at the plastic zone at the notch. When the sample can absorb no more energy, fracture occurs. Therefore, the absorbed energy difference between rPVC-sawdust composites and vPVC-sawdust composites is shown in Figure 4a, while the difference in the absorbed energy between rPVC-palm fiber composites and vPVC-palm fiber composites is shown in Figure 4b. The absorbed energy difference between rPVC-sawdust composites and vPVC-sawdust composites with fiber content of 2 wt% was higher (~ 4.8 kJ/m^2) than that of other PVC-sawdust composites (with 4, 6, 8 wt% fiber content). On the other hand, The absorbed energy difference between rPVC-palm fiber composites and vPVC- palm fiber composites with fiber content of 8 wt% was higher (~ 3.8 kJ/m^2) than that of other PVC-palm fiber composites (with 2, 4, 6 wt% fiber content).

Figure 4. The absorbed energy difference between: a) rPVC-sawdust and vPVC-sawdust composites, and b) rPVC-palm fiber and vPVC- palm fiber composites.

The Charpy impact strength test is typical ASTM tests used to determine toughness. This is because impact test signifies toughness, or impact strength, of a material that is the ability of material to absorb energy during plastic deformation. A material high impact resistance is said to be a tough material. Toughness is the combination of strength and ductility. To be tough, a material must exhibit both fairly good strength and ductility to resist cracking and deformation under impact loading. The above discussion on the impact strength results can be applied on toughness.

The average hardness values for the vPVC, rPVC and their composites are shown in Figure 5. The results of this study reveal that the average surface hardness values of rPVC and their composites were higher than that of vPVC and their composites. This is might be due to the presence of some additives such as calcium carbonate in rPVC, as mentioned previously. In addition, the results show that, hardness was increased slightly with increasing the fiber content. This was expected because an increase in the natural fiber levels in composite materials results in better hardness [24, 35]. Moreover, composites with sawdust showed to have slightly higher surface hardness values that those of composites with palm fiber. Sawdust and wood flour are the most common wood filler used in polymer composites and other wood-alternative material composites has made major advances in material performance [36]. Jaya et al. [37] declared that organic filler such as wood sawdust will be an alternative and vital reinforcement filler towards manufacturing composites as it can reduce the cost of raw material with better performance in composites.

It is important to clear that a higher hardness means a higher resistance to deformation, particularly permanent deformation, indentation or scratching. Although hardness testing does not give a direct measurement of any performance properties, it correlates with strength, ductility, wear resistance, and other properties. As found in the literature [22], hardness varies inversely with ductility and the deformations caused by a hardness indenter are of similar magnitude to those occurring at ultimate tensile strength in tensile strength test. This is because tensile strength and hardness are indicators of a material's resistance to deformation. Thus, tensile strength and hardness are proportional. This means that hardness increases with the increase in strength. Most importantly, a material that have a higher surface hardness, in general, considered to be more wear resistant [17].

Figure 5. Shore hardness of a) vPVC, b) rPVC and their composites.

It is essential to emphasis that rPVC from our domestic waste can be transferred into useful products in the field of manufacturing polymer composites. Further studies are needed to gain better understanding on these materials and their utilization in this field. In reality, PVC-NF composites are most often used in building construction applications, such as window/door profiles, decking, railing, and siding, representing about 22% of the marketing. Fiber content varies from 30 to 70% in these types of composites. Compared with unfilled PVC, PVC composites are more expansive [12]. Consequently, it is appealing to study properties of composites made with rPVC (from domestic waste) and local nature fiber contents (e.g. sawdust, palm, olive stone, alpha grass, etc.) vary from 30 to 70%. Generally, high fiber content results in better properties and good composite performance.

4. Conclusions

Polymer composites made with vPVC and rPVC and different natural fibers (palm fiber and sawdust) were prepared successfully using mini-extruder and mechanical properties such as impact strength and hardness were evaluated. The fiber content in the prepared composites was varied from 2 to 8 wt%. Without surprise, this investigation showed that the fiber type and fiber content play an important role in impact strength and hardness properties of PVC-NF composites. The impact strength properties of rPVC-NF composites were noticeably different from vPVC-NF composites. The results raveled that the incorporation of palm fiber and sawdust into vPVC matrix showed to decrease the impact strength. Opposite effect was observed when palm fiber and sawdust were incorporated into rPVC matrix. vPVC-NF composites show, regardless of the employed type of fiber, a comparable behavior and maximum impact strength at 8 wt% fiber content. Likewise, rPVC composites with both types of fibers show a comparable behavior and maximum impact strength at 2 wt% fiber content.

The results of hardness pointed out that the average surface hardness values of rPVC and their composites were higher than that of vPVC and their composites. As with impact properties, this is because different rPVC products are expected to have different density and formulations of additives such as calcium carbonate, lubricants, stabilizers and impact modifiers. In addition, the results show that, hardness was increased slightly with increasing the fiber content. However, it is important to conclude that PVC-sawdust composites (with either vPVC or rPVC) showed to have better impact strength and slightly higher surface hardness values that those of palm PVC-fibers composites.

The important feature of composite materials is that they can be designedand tailored to meet diff erent requirements. Accordingly, more work in this field still needed to explore the scope and limitations of these materials. The future researches must focus on the development of such materials with balance of structure and property in order to gain excellent properties and superior performance with low cost and manufacturability. Also, attention should be paid more to the use of PVC waste (generally plastic waste) and green materials to provide alternative way to solve the problems associated with plastic waste and agriculture residues.

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