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Mechanical Properties Investigation of HDPE Matrix Composites Reinforced with Wheat Straw Fibers

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Abstract

The present article summarizes an experimental study on the mechanical behavior of high density polyethlene (HDPE)/ wheat straw (WS) composites. The mean goals of this investigation were using of wheat straw (WS) as a filler (reinforcer), effectiveness of straw flour fiber with different size (10-30 mesh as fine) and (30-50 mesh as coarse) on mechanical properties of composites and effect of maleic anhydride (MA) as a coupling agent treatment is performed to improve interfacial adhesion between the fibers and HDPE matrix. Generally, (16) treatment were conducted as (8) treatment of HDPE with 10, 20, 30, 40% coarse wheat straw with (0.5, 1.0, 1.5, 2.0) MA, 8 treatment of (HDPE) with 10, 20, 30, 40% fine wheat straw (WS) with (0.5, 1.0, 1.5, 2.0) MA, (HDPE) (WS). This study focused upon tensile strength, flexural, impact strength and hardness of reinforced polyethylene. The results showed that increase wheat straw rate to 30% in both fine and coarse, improved [tensile, strength hardness flexural and impact strength] values, Fine (WS) particles sample showed better, then coarse (WS) when addition for HDPE as fiber to produced composite material.The optimum formulation for the (HDPE and WS) composites on the mechanical properting is (30wt.%WS as fine-HDPE-1.5wt.%MA).

دراسة الخواص الميكانيكية للمواد المركبة المتكونة من البولي اثيلين عالي الكثافة كاساس مع قش الحنطة كالياف تقوية

الخلاصة

الدراسة الحالية تعتبر محاولة لدراسة سلوك الخواص الميكانيكية لمادة مركبة ناتجة من بولي اثيلين عالي الكثافة HDPE كمادة اساس مع قش (تين) الحنطة Wheat Straw كالياف تقوية، ان الهدف المتحقق من استخدام هكذا نوع من الالياف ذات الاحجام المختلفة (mesh size) (10-30 mesh) من النوع الناعم، (30-50 mesh) النوع الخشن هو تحسين الخواص الميكانيكية للمادة المركبة الناتجة وباختلاف نسبي بين النوع الناعم والخشن، كذلك تم استخدام عامل الربط (Coupling Agent) من نوع Maliec Anhydrid الذي عمل مع تحسين التلاصق بين البولي اثيلين عالي الكثافة وقش الحنطة.

ستة عشرة معاملة تم القيام باجراءها ثمانية للقش الناعم والاخرى للخشن حيث استخدمت نسب وزنية مختلفة (10, 20, 50, 40%) من قش الحنطة بنوعيها الناعم والخشن كالياف تقوية وبوجود وعدم وجود عامل الربط (MA) وبنسب وزنية مختلفة ايضاً (0.5, 1.0, 1.5, 2.0%). تم دراسة مقاومة الشد Tensile Strength ، مقاومة الانثناء Flexural Stength، Hard ness و Impact Strength للمادة المركبة الناتجة. افضل خواص ميكانيكية تم الحصول عليها عند النسبة الوزنية (30%) وفي كلا الحجمين الناعم والخشن من قش الحنطة. بكل ظروف الدراسة تم اثبات ان الحجم الناعم من الالياف يعطي خواص ميكانيكية افضل من الحجم الخشن، كذلك تم التوصل الى ان افضل خواص حصلت في التركيب :

30%wt.WS fine-HDPE-1.5%wt. MA

Introduction

New properties, lower prices and reuse of polymers are needed to meet demands of today's society and therefore of the polymer industry. Polymer is the technical name for what is more generally known as plastic, [1]. Plastic are used by almost everybody since (for example) most domestic machines have a housing, which is made out of it [1,2]. Fiber reinforced thermoplastic composites have emerged as a major class of structural material in the field of aerospace, automobiles, construction, etc. These material are characterized by easy processibity, good dimensional stability, and excellent mechanical performance [3,4].

In general , materials may be selected and specified different properties. Here, though, we are mainly interested in composites for structural applications. The two properties of particular relevance are stiffness and strength, preferably combined with low weight [5]. Fiber reinforcement may be used in several different forms or arrangements, depending on the application and manufacturing route. They are categorized firstly, in terms of length: (I) Short (less than 10mm)-used mainly in thermoplastic moulding compounds. (II) long (10-20mm)-used in chopped strand mat and in thermosetting moulding compounds. (III) continuous fibers, it offer the highest mechanical properties, and give the possibility of using specific orientations to give the composite directional properties. The are available as lengths of fabric in many different woven, knitted or stitched forms, all of which have different properties, processing characteristic and costs. These include: Unidirectional, biaxial, multiaxial and random. Generally, both the fibres and the form of the reinforcement contribute to the properties of the composite, while the manufacturing, cycle is primarily determined by the matrix [6].

The growing interest in using natural vegetable fibers as a reinforcement of polymeric based composites is mainly due to their renewable origin, relative high specific strength and modulus, light weight and low price [7]. Recent developments in natural fibers such as jute, sisal, coir, flax, wheat straw, etc, have shown that it is possible to obtain well performing materials, using environment freindly reinforcements [8]. The mechanical properties of natural fiber-reinforced composites can, in fact, be further improved by chemically promoting a good adhesion between the matrix and the fiber. Other advantage of utilizing natural fibers are related to their cycle of production that is economical and their ease of processing which demands minor requirements in equipment and safer handing and working conditions with respect to glass fibers. In any case, the most interesting feature coming from the employment of natural fibers is the extremely favorable environmental impact, due to the fact that natural fibers are produced from a renewable sourse and are biodegradable [9]. On the other hand , low thermal stability, high moisture up take, and limited fiber lengths, represent some of the disadvantage related to the utilization of natural fiber composites [10].

To enhance the compatibility of the two phase in such composites, a compatibilizer or coupling agent is normally added, to the Mixture. Many researchers have reported improvements in mechanical properties when a compatibilizer was used or the fibers were chemically modified prior to mixture [11,12].

In the present investigation , the mechanical characteristics of various wheat straw (WS)-high density polyethylene (HDPE) composites have been investigated. The effect of coupling agent maleic anhydride (MA) treatment on the mechanical properties of composites have been studied.

Materials and Methods

Raw Materials

(a) High density polyethylene (HDPE), powder was supplied by Basrah Petrochemical Company General with a density 950 kg/m^3. Its melting temperature (132°C) and melt flow index (MFI) 6g/10 min, was used as the base polymer matrix.
(b) Wheat straw (WS) fibers, having a different size (10-50 mesh) obtained from (Al-Tajiah fields near Babylon University), was used as the reinforcing fiber.
(c) Maleic anhydride (MA), supplied by Univoyal chemicals, MB226D. was used as a coupling agent.

Fiber Treatment

The Fibers, scoured in detergent at 65°C for 30 min. to remove dirt and core material followed by washing with distilled water, were dried in oven at 60°C. The dried fibers were cut and grinding to suitable mesh size.

Composites Preparation

Polymer, fibers and coupling agent were initially weighed and bagged according to the various fiber contents indicated in Table (1). The composition of each formulation is also shown.

The compounds were prepared by means of hot –rolls at a temperature 160°C, which is above the melting point of the polyethylene, for 30 minutes. The wheat straw (WS) previously a cut and grindind to (10-50 mesh) size, and dried in an oven at 60°C for 5 hours ensure that moisture contents were blow 0.5%. Once the polymer was melted, the appropriate percentage of fibers was added to the polymer. Immediately after mixing, the material was extruded [single screw extruder, C.W. Brabender. I. P. with ascrew L/D of 30:1 of 60 rpm] into granules, and then injection molded to obtain standardized specimens. Using compression molded (3 ton) to produce sheet 2mm and 3mm thickness for various testing.

Conditioning

After preparation, all specimens were conditioned in a a humidity controlled room at 25°C and 50% relative humidity for at least 48 hours prior testing.

Composite Characterization

- Tensile testing , sample were cut according to ASTM D638. the machine that was used for the testing of tensile properties is University testing Mashine (PHYWE). The test was conducted at velocity 5mm/s at ambient temperature.
- Flexural test was also using Universal testing Mashine (PHYWE) according ASTM D790. for testing , the support span was fixed at 100mm and the rate crosshed motion at 3 mm/min.
- The Izod impact machine was used for this testing. The dimension of the sample specimen conform to ISO179.
- Hardness Test was used Universal testing Mashine (PHYWE), the samples were cut according to ASTM D785.

Table 1: Composition of Evaluated Formulation (wt.%)

Formulation	Specimen Code*	Resin Content	Coupling agent**
	………%..........	………%..........	………%..........
1	HDPE-WS-10(fine)	90	-
2	HDPE-WS-20(fine)	80	-
3	HDPE-WS-30(fine)	70	-
4	HDPE-WS-40(fine)	60	-
5	HDPE-WS-10(coarse)	90	-
6	HDPE-WS-20(coarse)	80	-
7	HDPE-WS-30(coarse)	70	-
8	HDPE-WS-40(coarse)	60	-
9	HDPE-WS-30(fine)	69.5	0.5
10	HDPE-WS-30(fine)	69	1.0
11	HDPE-WS-30(fine)	68.5	1.5
12	HDPE-WS-30(fine)	68.0	2.0
13	HDPE-WS-30(coarse)	69.5	0.5
14	HDPE-WS-30(coarse)	69	1.0
15	HDPE-WS-30(coarse)	68.5	1.5
16	HDPE-WS-30(coarse)	68.0	2.0

* HDPE= high density polyethelen; WS= wheat straw; fine (10-30 mesh); coarse (30-50 mesh);

** coupling agent = Maliec anhydride.

Results and Discussion

Figures (1-4) illustrates the characteristic (mechanical properties –wheat straw) curves on the studied fiberous reinforcement. It is observed that the mechanical properties such as tensile strength, flexural strength, hardness, and impact strength of HDPE-wheat straw (WS) composites increased linearly with increase in fiber loading from 10 to 30%. An Approximate increase of 46, 45, 69, and 61% in tensile, flexural, hardness and impact strength respectively (fine wheat straw) was observed with 30% wheat straw (WS) -filled compositen as compared with the virgin matrix. A similar improvement in the mechanical properties where increase of 37, 30.5, 315 and 41% in tensile, flexural, hardness and impact strength respectively (coarse wheat straw). This results approximately agrees with the results (Alireza *et al.,* 2006) [13]. This behavior is primarily attributed to the reinforcing effect of the fibers leading to a uniform stress distribution from the continous polymer matrix to the dispersed fiber phase.

However, beyond 30% of fiber loading there was a notable reduation in mechanical properties of composites. This decrease at high fiber loading implied poor fiber-matrix adhesion, which promoted micro crack formation at the interface as well as nonuniform stress transfer due to fiber agglomeration within the matrix [4]. On the other hand for high concentration (40% in weight), the polymer matrix was not continuously distributed and most wheat straw fibers directly contacted one another, thus resulting in poor adhesion at the interface. This situation was improved when the amount of thermoplastic larger than (up 65%) that of wheat straw (WS) fibers in weight, most fibers were enveloped by the polymer matrix when polymer phase were abundant in composite, this was due that the total surface contact area of individual fibers with the matrix was close to the maximum value, and the dispersion resistance reached the maximum value [14].

In all figures (1-4) shows that the fine wheat straw flour fiber samples showed better in mechanical properties compared with coarse wheat straw flour fiber, it is evident that this behavior is primarily attributed to improved fiber – matrix interfacial adhesion, which increases the friction between the polymer and the fibers thereby resulting in mechanical properties [4]. On the other hand, the small diameter can not contain significantly laug cracks, so the material is much stronger [14].

The mechanical properties of the wheat straw (30% by weight fine and 30% by weight coarse)- reinforced high density polyethylene HDPE composites, as a function of maleic anhydride MA weight are shown figures (5-12). From all figures, it is evident that the mechanical properties of the composite increase with increase the coupling agent (MA) from 0.5-1.5%. this mainly due to the reaction of (MA) with radicals for med by the functionalisation of HDPE leading to the grafing (of MA) on to HDPE. On the other hand the wheat straw (WS) was randomly distributed and separated in a continuous thermoplastic matrix. It was encapsulated or enveloped by the thermoplastic matrix mainly with mechanical connection, without the coupling treatment, the interfacial region was weakly linked, under loading, composite were mainly damaged along the loose and weak interfacial connections between wheat straw fibers and thermoplastics and followed a cohesive mode. For composites with coupling treatment , most wheat straw fibers were combined with thermoplastics through covalent bonding or strong interfacial bounding and the interface was strengthened with coupling agents [15].

The composites prepared using 1.5% MA by weight exhibited optimum mechanical properties. However, with a futher increase in MA weight from 1.5-2%, a maginal decrease in mechanical properties was observed, this behavior may be attributed to the migration of excess MA around the fibers, causing self-entanglement among themselves rather than the polymer matrix resulting in slippage [14].

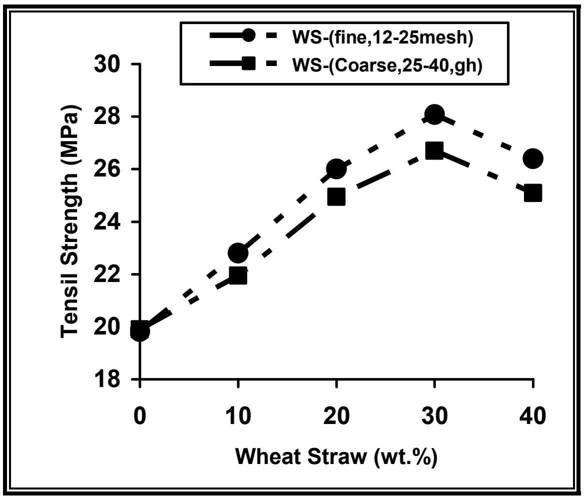

Fig. (1): Influence of Wheat Straw (WS) Fiber Weight Percentage on Tensile Strength of WS Fiber – HDPE Composites.

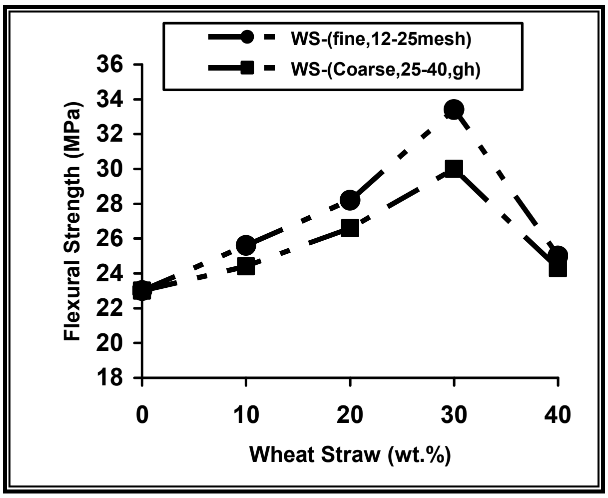

Fig. (2): Influence of Wheat Straw (WS) Fiber Weight Percentage on Flexural Strength of WS Fiber – HDPE Composites

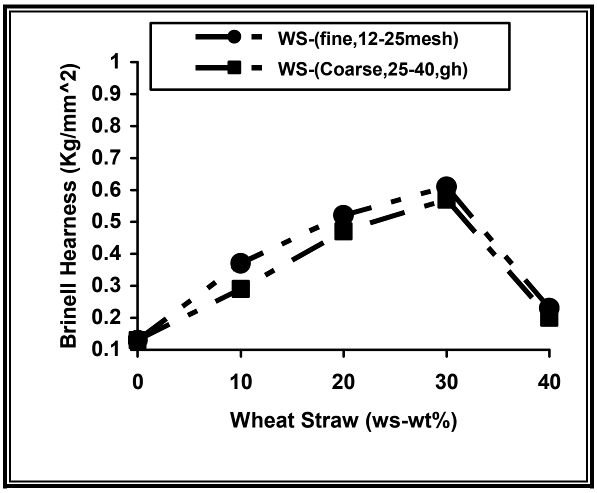

Fig. (3): Influence of Wheat Straw (WS) Fiber weight Percentage on Brinell Hardness of WS fiber – HDPE Composites

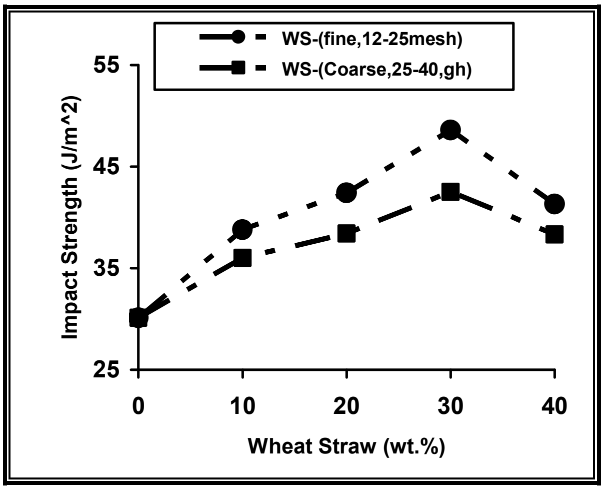

Fig. (4): Influence of Wheat Straw (WS) Fiber Weight Percentage on Impact Strength of WS fiber – HDPE Composites

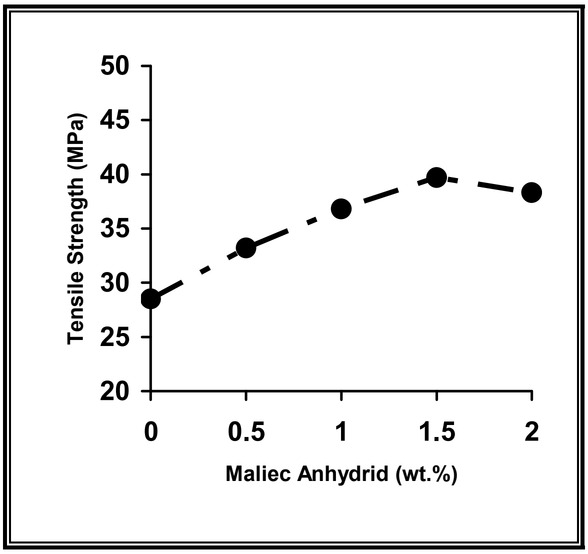

Fig. (5): Influence of Maliec Anhydrid (MA) Coupling Agent Weight Percentage on Tensile Strength of Wheat Straw (30% fine) Fiber – HDPE Composites.

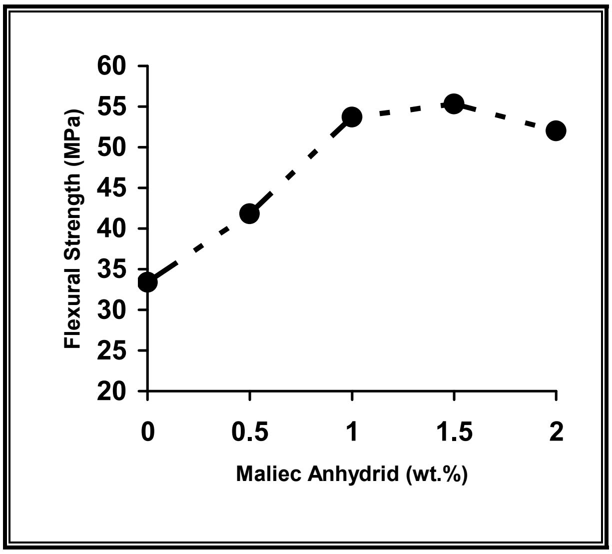

Fig. (6): Influence of Maliec Anhydrid (MA) Coupling Agent Weight Percentage on Flexural Strength of Wheat Straw (30% fine) Fiber – HDPE Composites

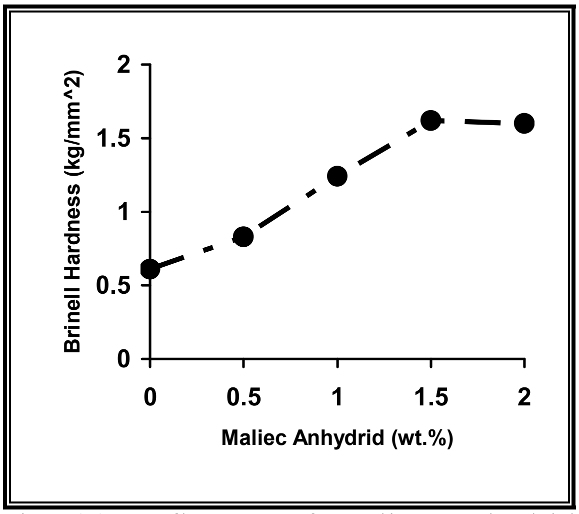

Fig. (7): Influence of Maliec Anhydrid (MA) Coupling Agent Weight Percentage on Brinell Hardness of Wheat Straw (30% fine) Fiber – HDPE Composites

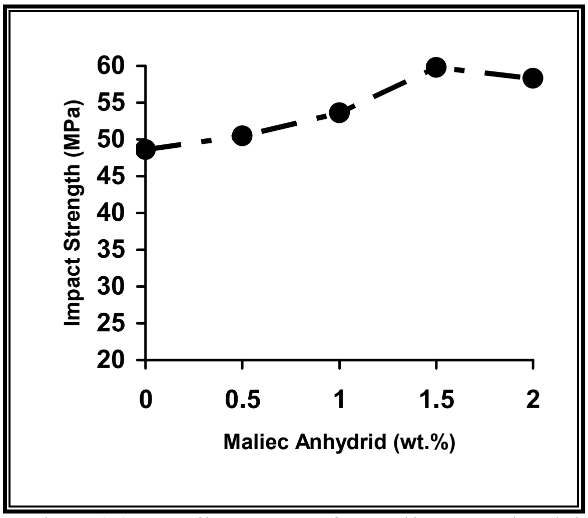

Fig. (8): Influence of Maliec Anhydrid (MA) Coupling Agent Weight Percentage on Impact Strength of Wheat Straw (30% fine) Fiber – HDPE Composites

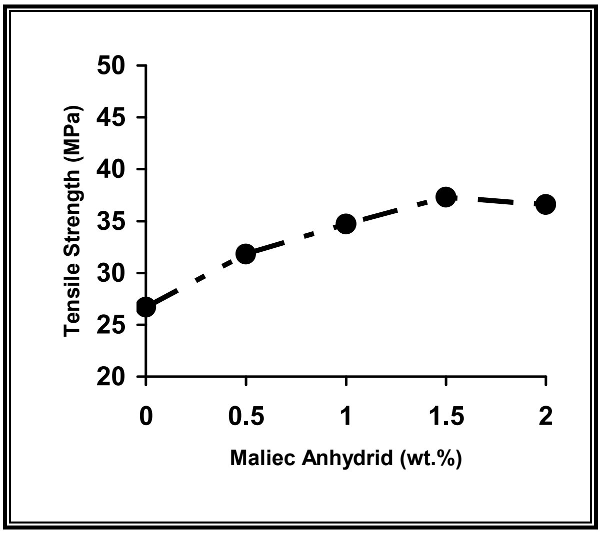

Fig.(9): Influence of Maliec Anhydrid (MA) Coupling Agent Weight Percentage on Tensile Strength of Wheat Straw (30% coarse) Fiber – HDPE Composites

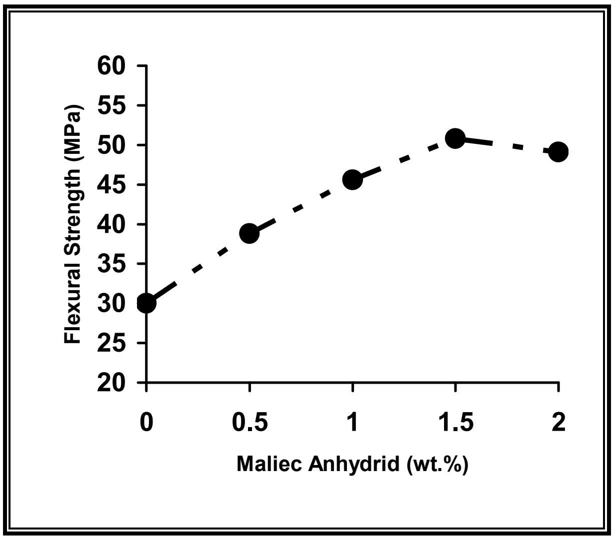

Fig.(10): Influence of Maliec Anhydrid (MA) Coupling Agent Weight Percentage on Flexural Strength of Wheat Straw (30% coarse) Fiber – HDPE Composites

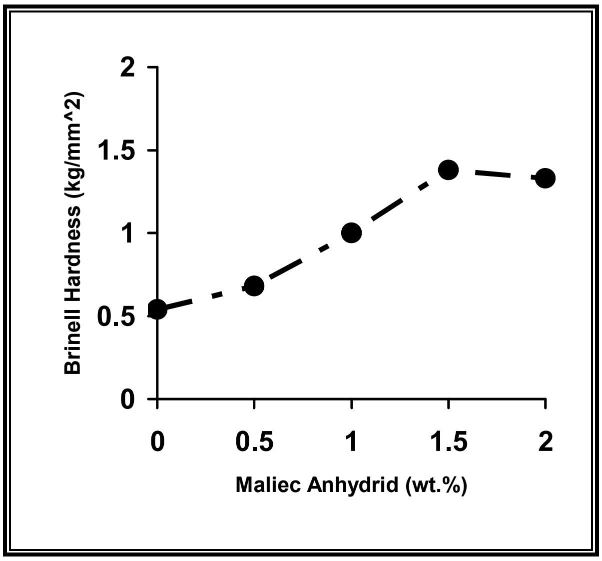

Fig. (11): Influence of Maliec Anhydrid (MA) Coupling Agent Weight Percentage on Brinell Hardness of Wheat Straw (30% coarse) Fiber – HDPE Composites.

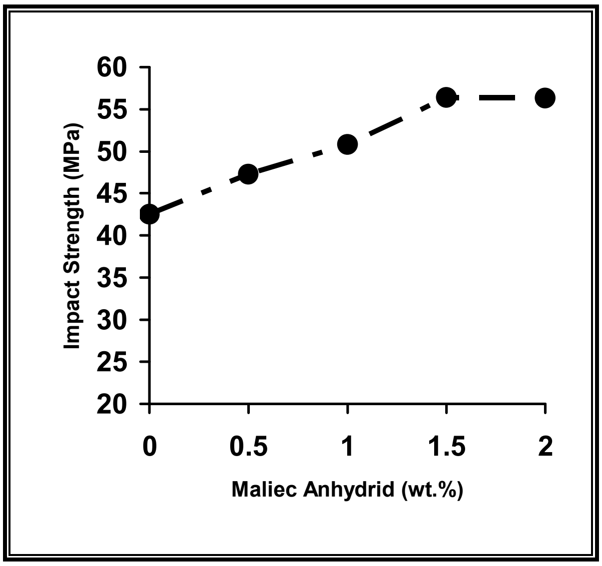

Fig. (12): Influence of Maliec Anhydrid (MA) Coupling Agent Weight Percentage on Impact Strength of Wheat Straw (30% coarse) Fiber – HDPE Composites

Conclusion

I. The overall trend shows a marked increase in a mechanical properties of composites [HDPE-WS] with increasing of wheat straw (WS) content (10-30% wt.).

II. Coupled composites have higher mechanical properties values than did uncoupled composites. This was attributed to the improved interface quality due to the presence of the compatibilizer.

III. Low cost of wheat straw (WS) fiber can be used as an effective reinforcement with a fiber loading of 30% to prepare high performance WS-HDPE composites.

IV. Generallys the composites content wheat straw fiber fine [10-30 mesh] introduced mechanical properties better than composites content wheat straw fiber coarse [30-50 mesh].

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