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EXPERIMENTAL INVESTIGATION OF MICRO-HARDNESS BEHAVIOUR OF DUAL BLENDED REINFORCED POLYMER MATRIX COMPOSITES OF FIVE SELECTED FORTIFIERS

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Abstract

The abounding views on composite's damage potential evaluations restricts composite's life-cycle computations and associated decision making to metal-rooted composites due to the dearth of literature contributions on agro-rooted hardness evaluations of polymer composites. In recent times, nevertheless, appreciation has expanded that particulate forms of selected agro-rooted reinforced polymer composites such as orange peels, periwinkle shells, palm kernel shells, egg shell and coconut shells are as well substantial drivers of micro-hardness information for the life-cycle cost computations of automotive parts replacements due to their cassinogenic influences (i.e. brake pads). Rooted on experimental arguments, overwhelming facts are provide in a new way concerning the hardness values of some hitherto unexplored dual blends of reinforced agro-based composites mentioned earlier. Hardness tests was carried out on epoxy composites based on the dual reinforcement mixtures of (OP_p/CS_p), (PKS_p/CS_p), (PSp/ES_p), (OPp/PS_p) and ($PKSp/ES_p$) in polymer composites of volume fractions. The composites were post-cured under three different temperatures, 80, 100 and 120^{o}C. For the 80^{o}C post-cured composites. The (15PKSp/10CSp) and (20PKSp/5CSp)% composites (formulation 2) had the highest hardness of 29.3 HV under all the post-cured conditions. A second aspect of the work is to explore an investigation on the relationship between the hardness, tensile, impact and flexural strength properties of five dual particle filled epoxy composites. The different relationships for each composite were represented by mathematical models with the hardness fitted as the response variable while the remaining properties were adjusted as the predictor variables at six levels of observations using the multiple regression analysis. A confidence interval of 95 % and p-value of < 0.05 were used in the build up to the models and each model showed good significance and high correlation (R^2) values with the (PKS_p/ES_p) model obtaining the highest $R^2$of 0.972. The models helped to understand which of the predictor variables was most relevant to the hardness response variable of the composite which will help to make informed decisions on practical usage. The compelling results therefore influence the current research landscape and perceptions on micro-hardness determinations in an effort for more effective damage potential evaluations of polymer composites.

Keywords: *Mechanical properties, variables, mathematical model, multiple regression analysis, correlation.*

Introduction

General

Damage potential evaluations is a form of scientific activity carried out on composites with the use of hardness values among others, to predict the probable cost of damages to composites in its life-cycle so as to manage the manufacturing cost of the composite, and integrate the information to others at the planning stage [1-7]. Scholars, nevertheless, progress to deliberate on how to reduce the life-cycle cost of composites [8]. The abounding stand point is that through much progress has been made concerning life-cycle cost evaluations of some composites [8]; a serious omission of

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concern is the emerging environmental cost consequences such as cassinogenic effects of brake pad composites currently over looked, which gives a false impression of the cost at present. To correct this abnormally, scholars have suggested a migration of resources to fortifiers of agro-based composites with origins such as orange peels [9-11], coconut shells and products [12-14], periwinkle shells [15-17], palm kernel shells [18-19] and egg shells [20-22] with the passage of time, calls to synergic-ally benefit from reinforcement with their varied complementary characteristics has brought blends into the composite industry as a work. While this idea is expanding with success in the metal matrix composite development area [21, 22], the idea is certainly not known and experimented in the polymer composite arena. Thus far, nevertheless, composite scholars have not explicitly contemplated evaluating the microhardness of the dual blends of reinforcements of particulate coconut shells, periwinkle shells, palm kernel shell, orange peels and egg shells in epoxy composites.

Given the contrasting literature viewpoint and the information available on polymer composites, it is compellling to search for more useful alternatives to existing brake pad composites [23-26]. For instance, a closer analysis of the micro-hardness attributes of dual blends of reinforcements of selected agro-based polymer composites is necessary. To tackle this opening, in this research, an experimental investigation is embarked upon as particulate blends of orange peels, periwinkle shells, palm kernel shells, egg shells and coconut shells are made in duality under room temperature and humidity conditions. Specially, three random positions of the fabricated composites were analysed for micro-hardness and the averages taken to avoid variability problems. To produce a wide range of results, the post-curing activity to improve on the property performance of the composites were embarked upon. For this activity composites were post-cured at 80°C, 100°C and 120°C, respectively and the results reported in the current research.

The present research complements literature methods to both damage potential evaluation and the building of composites in a number of manners [3,5,7]. First, the current research provides a largely wide and an effective perspective to elaborate on the threshold of hardness for some relatively tough materials such as periwinkle and egg shells and also the less tough characteristics of other materials such as particulate orange peels. Nevertheless, orange peels are known for its appealing lubricating properties. The combined fortifiers with the new elevated hardness property that it presents in view of the complimentary properties they exhibit provides a significant shift away from the conventional methods of single-reinforced composite fabrication, development and analysis. Second, by experimenting at different post curing temperatures, the paper has been able to reveal the high performance transforming attributes of post-curing of polymer composites and extends the understanding of researchers on the potentials of exporting higher temperature scales for the post-curing of the selected polymer composites. Third, a new direction of reinforcement blending in polymer composites is initiated that could trigger research into tri- and multiple blending of reinforcements in polymer composites and such an understanding may have a long-lasting impact on the polymer composite development field by way of reducing the life-cycle cost of composites.

Problem formulation

A principal challenge in the present composites made of single reinforcement is the brittle nature of some the developed composites. In addition, cost is a major threat to the product sales as the customers have competing demands to spend the hard-earned money on. Furthermore, wastes have been a key challenge in the Nigerian society as government spends huge financial resources for clearing and maintenance of waste deposition and depositing sites. However, wastes are of tremendous importance as fortifiers in the composite industry owing to their abundance at source and light weight attribute. It is therefore compelling to develop an approach necessary to process these wastes as reinforcements for composites to capture the cost reduction, brittleness and environmental threat challenges of wastes in the Nigerian society and the developing countries at large. Through the current research, the developments of dual mixed fortifiers based on the following particulates are tested for hardness: particulate coconut shells, orange peels, periwinkle shells, palm kernels shells and egg shells.

This research is not available in the literature concerning hardness either for composites specifically or in the generally science of engineering materials. The hardness examination is pursued through the impacting of a torque sustained for a period, which creates indentation on the material. It is therefore essential to experimentally determine the value of hardness and establish a possible relationship between hardness and other mechanical properties, for instance, impact, fracture and tensile strength for a comprehensive visualization of the mechanical properties of the composite materials being developed. This solution to the above mentioned concerns is part of the focus of the present research. The study is anticipated to offer a cost-competent and green option composite product for use as brake pads in the automobile industry.

In the following sections, the literature review is brief. This is followed by the experimental methodology. The section that follows this contains the results from the research. This is then ended by a section on the conclusion of the research.

Literature review

Recently as well as a few years ago, independent studies were respectively conducted by Gurbuz and Mutuk [27] and Daoush and Elkady [28] on the significance of hardness appraisal in the composite research domain. They highlighted the manner in which hardness influenced the production of alumina short fibres/nickel matrix composites (i.e. [28]) and graphene fortified titanium composites, respectively [27]. These examples are in several other documentations for applications in electrochemical deposits [29] cementing integrated density [30], railheads [31], films [32], heat treatment [33]. Other examples of hardness have been established in Harikrishna et al. [34] and investment casting [35].

Evidence from the composite literature advocates that micro-hardness are imperative contributors to the appraisal of composite’s state of degradation in the composite’s life-cycle analysis. Data demonstrate that degradation is not only related to the hardness of the composite but also the Young’s modulus of the composite as well [36]. Hardness as a degradation factors has also been emphasized in several reports [37-41]. Micro-hardness and its degradation effects has been completed with information on microstructure [42-45]. Hardness has also been linked to pitting confrontation [46]. Microhardness also has been linked to several other issues or concepts in the composite domain such as cryogenic treatments [47]. Up till now, scholars in the area of composite development first and foremost examine hardness as a composite performance determinant for degradation measurement merely when single reinforcements is considered in most cases. This viewpoint is limited as no synergic benefit are passed to other reinforcements. However, by considering dual blends of reinforcements to be added to the polymer matrix, the composite industry stands to benefit hugely from the synergy. First, an expanded life-cycle and operational period is certain. Second, the quality of search for the best mix is enhanced significantly. Third, a reduced cost of composite manufacturing is guaranteed. Fourth, an enhanced mechanical properties of the polymer composite is a huge possibility. Thus, the existing model of hardness must change to the promising one in which dual blends of reinforcements for polymer composites.

Highlighting the restrictions in the viewpoint concerning single reinforcement introduction in composite fabrication, an expanding body of investigations rooted in reinforcement development for water absorption property evaluation reveals that when two agro-rooted reinforcements are used in water absorption experiments, there is a complimentary benefits and synergic advantages of mixing two reinforcements. Verification of the fact was done on samples of orange peels and coconut shell in particulate forma. A higher water absorption performance resulting in lower water intake was recorded for the samples [48]. Thus, if dual reinforcement blends of coconut shell and orange peel particulates are essentially useful for water absorption process as the reinforcements was advocated for use in water absorption composite development, then the dual blends of reinforcements with hardness characterization related to polymer composite indicates that dual blends of reinforcements is possibly an essential but under-investigated matter in polymer composite development.

Procedure

The specimen was mounted on the specimen holder of the Vickers hardness machine. Then, at the press of a control, indentation was conducted on the specimen. The reading was made. The position of the specimen is adjusted to the second point, which is taken at random such that a second reading is made. A re-adjustment of the position to a third point is made for the identification to take place in a third time at a third location. Reading of the third position's value is made. The average of the reading is made and this represents the hardness value for the specimen, given in HV. The specimen number or label is ensured to be intact with code such that the volumetric ratio computations are known and one specimen could be distinguished from the another.

The research scheme for the whole body is given in Fig. 1.

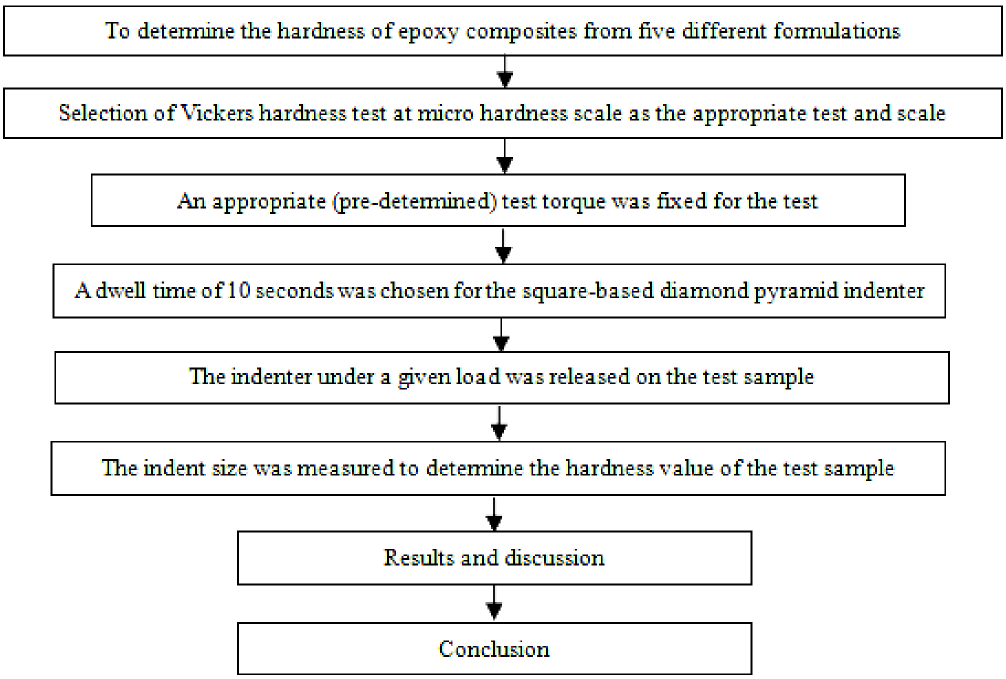


Fig. 1. Research scheme

The following is the flow of information for obtaining the hardness value (Fig. 2).

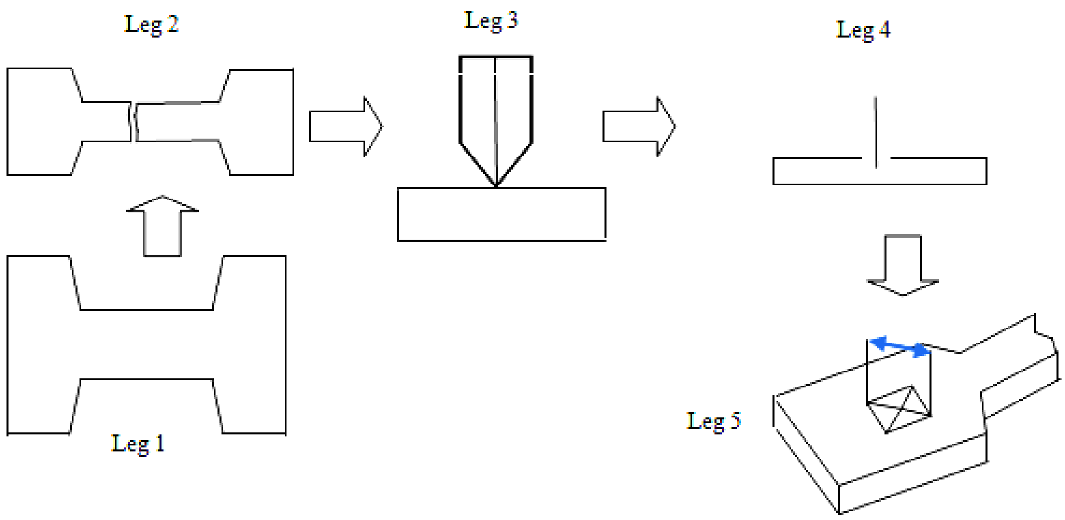


Fig. 2. The Five-leg hardness sample production process

[Key: Stage: (1) Tensile specimen used for hardness test before fracture; Stage: (2) Tensile specimen used for hardness test after fracture; Stage: (3): Cross section of hardness sample with before indentation; Stage: (4): Cross section of hardness sample with after indentation; Stage: (5): Top section of hardness sample with after indentation showing diagonal of indentation]

Results

Hardness test results

The following Tables 1 to 3 show the results of hardness for the different post-cured temperatures of 80°C, 100°C and 120°C

Table 1. Hardness test results for reinforced samples at 80°C post-cured temperature

				Readings	
S/N.	Formulation 1: OP_P/CS_P	HV1	HV2	HV3	Average of Vickers'
1	(25OPp)%	14.60	16.00	19.60	16.70
2	(20OPp,5CSp)%	19.60	17.60	19.50	18.90
3	(15OPp,10CSp)%	16.70	11.80	17.60	15.30
4	(10OPp,15CSp)%	18.70	19.40	18.50	18.80
5	(5OPp,20CSp)	21.50	20.70	21.90	21.30
6	(25CSP)%	17.60	22.90	14.30	18.20
	Mean	18.12	18.07	18.57	18.20
				Readings	
S/N.	Formulation 2: PK_p/CS_P	HV1	HV2	HV3	Average of Vickers'
1	(25PKSp)%	20.50	22.80	20.50	21.20
2	(5PKSp20CSp)%	18.70	18.40	17.60	18.20
3	(10PKSp,15CSp)%	20.80	18.80	21.20	20.20
4	(15PKSp,10CSp)%	26.60	29.00	32.40	29.30
5	(20PKSp,5CSp)%	26.60	29.00	32.40	29.30
6	(25CSP)%	17.60	22.90	14.30	18.20
	Mean	21.80	23.48	23.07	22.73

Table 1 (cont). Hardness test results for reinforced samples at 80^{o}C post-cured temperature

		Readings			
S/N.	Formulation 3: PS_P/ES_P	HV1	HV2	HV3	Average of Vickers'
1	(25PSp)%	18.90	18.90	13.00	16.90
2	(20PSp,5ESp)	20.80	22.20	22.50	21.80
3	(15PSp,10ESp)%	27.40	23.40	23.20	24.60
4	(10PSp,15ESp)%	21.40	23.50	20.00	20.10
5	(5PSp,20ESp)%	24.80	21.50	20.40	22.20
6	(25ESP)%	22.20	26.50	22.10	23.60
	Mean	22.66	21.90	19.82	21.12
		Readings			
S/N.	Formulation 4: OP_p/PS_P	HV1	HV2	HV3	Average of Vickers'
1	(25OPp)%	17.00	14.70	15.70	15.80
2	(20OPp,5PSp)%	16.00	15.70	14.80	15.50
3	(15OPp,10PSp)%	18.20	12.00	13.00	14.40
4	(10OPp,15PSp)%	20.50	25.80	27.70	24.60
5	(5OPp,20PSp)%	14.60	16.00	19.60	16.70
6	(25PSP)%	18.90	18.90	13.00	16.90
	Mean	17.53	17.18	17.30	17.32
		Readings			
S/N.	Formulation 5: PK_p/ES_P	HV1	HV2	HV3	Average of Vickers'
1	(25PKSp)%	20.50	22.80	20.50	21.20
2	(20PKSp,5ESp)%	12.00	20.00	18.20	16.70
3	(5PKSp,10ESp)%	31.70	23.10	24.70	26.50
4	(10PKSp,15ESp)%	23.50	20.90	15.60	20.00
5	(5PKSp,20ESp)%	14.30	21.10	24.00	19.80
6	(25ESp)%	22.20	26.50	22.10	23.60
		20.70	22.40	20.85	21.30

Table 2. Hardness test results for reinforced samples at 100^{o}C post cured temperature

		Readings			
S/N.	Formulation 1: OP_P/CS_P	HV1	HV2	HV3	Average of Vickers'
1	(25OPp)%	20.10	22.20	23.40	21.90
2	(20OPp,5CSp)%	17.70	19.00	18.20	18.30
3	(15OPp,10CSp)%	22.90	24.30	18.20	21.80
4	(10OPp,15CSp)%	27.60	25.40	24.00	25.60
5	(5OPp,20CSp)	19.00	19.70	19.80	19.50
6	(25CSP)%	20.90	22.60	24.60	22.70
	Mean	21.37	22.20	21.37	21.63
		Readings			
S/N.	Formulation 2: PK_p/CS_P	HV1	HV2	HV3	Average of Vickers'
1	(25PKSp)%	22.00	22.50	19.60	21.30
2	(5PKSp20CSp)%	25.40	26.90	27.90	26.70
3	(10PKSp,15CSp)%	22.90	23.10	24.90	23.60
4	(15PKSp,10CSp)%	27.10	24.00	25.90	25.60
5	(20PKSp,5CSp)%	30.30	22.60	24.40	25.70
6	(25CSP)%	20.90	22.60	24.60	22.70
	Mean	24.77	23.62	24.55	24.27
		Readings			
S/N.	Formulation 3: PS_P/ES_P	HV1	HV2	HV3	Average of Vickers'
1	(25PSp)%	20.90	22.00	26.60	23.10
2	(20PSp,5ESp)	21.40	20.70	20.50	20.80
3	(15PSp,10ESp)%	20.10	20.50	21.60	20.70
4	(10PSp,15ESp)%	23.30	22.30	22.50	22.70
5	(5PSp,20ESp)%	22.30	22.90	22.10	22.40

Table 2 (cont). Hardness test results for reinforced samples at 100°C post cured temperature

S/N.	Formulation 3: PS_P/ES_P	HV1	HV2	HV3	Average of Vickers'
6	(25ESP)%	18.10	19.20	20.80	19.30
	Mean	21.02	21.27	22.35	21.50
			Readings		
S/N.	Formulation 4: OP_p/PS_P	HV1	HV2	HV3	Average of Vickers'
1	(25OPp)%	20.10	22.20	23.40	21.90
2	(20OPp,5PSp)%	18.80	14.20	14.70	15.90
3	(15OPp,10PSp)%	19.30	18.40	17.40	18.30
4	(10OPp,15PSp)%	19.50	21.40	22.20	21.00
5	(5OPp,20PSp)%	17.50	20.50	24.20	20.70
6	(25PSP)%	20.90	22.00	26.60	23.10
	Mean	19.35	19.78	21.42	20.15
			Readings		
S/N.	Formulation 5: PK_p/ES_P	HV1	HV2	HV3	Average of Vickers'
1	(25PKSp)%	22.00	22.50	19.60	21.30
2	(20PKSp,5ESp)%	25.00	21.30	17.40	21.20
3	(5PKSp,10ESp)%	25.20	24.40	17.90	22.50
4	(10PKSp,15ESp)%	23.60	24.20	25.00	24.20
5	(5PKSp,20ESp)%	25.40	27.30	28.10	26.90
6	(25ESp)%	18.10	19.20	20.80	19.30
		22.82	22.9	22.18	22.58

Table 3. Hardness test results for reinforced samples at 120°C post cured temperature

			Readings		
S/N.	Formulation 1: OP_P/CS_P	HV1	HV2	HV3	Average of Vickers'
1	(25OPp)%	27.00	25.60	33.30	28.60
2	(20OPp,5CSp)%	19.30	22.00	22.70	21.30
3	(15OPp,10CSp)%	22.40	17.00	22.80	20.70
4	(10OPp,15CSp)%	16.20	18.90	18.10	17.70
5	(5OPp,20CSp)	25.90	23.00	23.40	24.10
6	(25CSP)%	25.50	21.40	24.20	23.70
	Mean	22.70	21.30	24.10	22.60
			Readings		
S/N.	Formulation 2: PK_p/CS_P	HV1	HV2	HV3	Average of Vickers'
1	(25PKSp)%	24.10	22.50	26.30	24.30
2	(5PKSp20CSp)%	23.10	24.30	20.30	22.50
3	(10PKSp,15CSp)%	22.30	20.40	24.10	22.20
4	(15PKSp,10CSp)%	20.50	19.20	19.90	19.70
5	(20PKSp,5CSp)%	20.10	18.50	23.80	20.80
6	(25CSP)%	25.50	21.40	24.20	23.70
	Mean	22.60	21.10	23.10	22.20
			Readings		
S/N.	Formulation 3: PS_P/ES_P	HV1	HV2	HV3	Average of Vickers'
1	(25PSp)%	22.00	21.90	22.50	22.10
2	(20PSp,5ESp)	21.30	20.80	22.50	21.50
3	(15PSp,10ESp)%	19.40	19.00	20.20	19.50
4	(10PSp,15ESp)%	18.30	22.00	23.90	21.40
5	(5PSp,20ESp)%	21.00	22.80	21.80	21.80
6	(25ESP)%	27.60	25.00	21.40	24.60
	Mean	21.60	21.90	22.10	21.80

Table 3 (cont). Hardness test results for reinforced samples at 120°C post cured temperature

		Readings			
S/N.	Formulation 4: OP_p/PS_P	HV1	HV2	HV3	Average of Vickers'
1	(25OPp)%	27.00	25.60	33.30	28.60
2	(20OPp,5PSp)%	20.60	16.40	16.30	17.70
3	(15OPp,10PSp)%	23.60	22.00	18.80	21.40
4	(10OPp,15PSp)%	20.40	21.60	18.00	20.00
5	(5OPp,20PSp)%	23.60	27.90	25.10	25.50
6	(25PSP)%	22.00	21.90	22.50	22.10
	Mean	22.90	22.60	22.30	22.60
		Readings			
S/N.	Formulation 5: PK_p/ES_P	HV1	HV2	HV3	Average of Vickers'
1	(25PKSp)%	24.10	22.50	26.30	24.30
2	(20PKSp,5ESp)%	22.30	22.10	22.80	22.40
3	(5PKSp,10ESp)%	22.30	21.50	21.70	21.80
4	(10PKSp,15ESp)%	26.80	24.80	27.10	26.20
5	(5PKSp,20ESp)%	28.70	21.20	20.40	23.40
6	(25ESp)%	27.60	25.00	21.40	24.60
	Mean	25.90	23.30	22.50	23.80

The hardness test for the newly developed epoxy composite formulations 1-5 were carried out on the hardness machine. Formulation 1 to 5 consist of dual mixtures of OP_p/CS_p, PKS_p/CS_p, PS_p/ES_p, OP_p/PS_p and PKS_p/ES_p, corresponding for the OP_p/CS_p blend (Formulation 1), six different samples with each containing different compositions were contemplated. These are (250Pp), ($200P_p/5CS_p$), ($150P_p/10$ (S_p), ($100P_p/15CS_p$), ($50P_p/20CS_p$) and ($25CS_p$). The different compositions were made from a combination of varying fibre volume fractions of the reinforcement in the epoxy composite used for the experimentation. For instance, the first sample in formulation 1 (i.e. 250) consist of 25% particulate orange peel and 0% coeci shell particulate composition of the particulate orange peel is 20% while that of the particulate coconut shell is 5%. In the same manner, the 3rd, 4th, and 5th and 6th samples could be interpreted of their compositions in orange peel particulate and coconut shell particulate. In a similar manner, the descriptions of the compositional nature for formulations 2, follows the pattern described above, while the reinforcements for formulation 2 are the blends of particulate palm kernel shells and coconut shells. This formulation 2 also consists of the following sample compositions: ($25PKS_p$), ($20PK_p$, $5CS_p$), ($15PKS_p$, $10CS_p$), ($20PKS_p$, $5CS_p$) and (25CSP)%. In formulation 33 following the procedures for formulations 1 and 2, the following sample composition were also tested for hardness ($25PS_p$), ($20PS_p$), $5ES_p$)%, ($15PS_p$, $10ES_p$), ($10PS_p$, $15ES_p$), ($5PS_p$), $20ES_p$) and ($25ES_p$)%.

Formulation 4 is a blend of particulate orange peel and periwinkle shells and consist of the following: ($250P_p$), ($200P_p/5$ PS_p)%, ($150P_p$/10PSp)%, (100Pp/$15PS_p$), ($50P_p/20PS_p$) and ($25PS_p$)%. In formation 5, the blends of palm kennel shell and egg shell particulates were made into six compositions of different samples as follows: ($25PKS_p$), ($20PKS_p/5ES_p$), ($10PKS_p/10ES_p$), ($5PLS_p/20ES_p$) and $25ES_p$)%. For the hardness experiment, it was noted that a modification in the compositions of the reinforcements of the epoxy composite has the tendency to reflect the influence on hardness changes in the composites. Following the ASTM standards, the points were randomly chosen on the hardness specimen and the hardness values of each of these points were measured. The average of the three evaluations were used as the hardness values in this experiment so as to avoid errors due to readings and equipment. The experiments were conducted on samples subjected to three different post-cored temperatures of 80, 100 and 120^0C.

Hardness outcome at 80 ^{0}C post-cored temperature

Table 1 shows that in formulation 1, the composition that has the highest average Vickers number is the (50Pp, 20CSp)% composite coconut shell particles are characteristically harder than particulates orange peels. Consequently, a higher volume fraction of CSp in the epoxy matrix of the (50Pp, 20CSp)% composite substantially surpasses the influence of the orange peel particulates. Thus, reflecting the higher status of the hardness of the CSp. Hence, their large presence in the epoxy matrix as particles and good particle matrix interface in the composite helps to resist shape chage due to indentation and consequently produced good hardness values. It could be added that the composite that produced the least hardness value was the (150P, 10CSp)% at the 80^0C post wring temperature. From this same Table 1, two composites, namely; (15PKSp, 10CSP) and (20PKSp, $5CS_p$) produced the best hardness values in a typically, particulates coconut shells and palm kernel shells appear to compete in high hardness values. However, the palm kernel shells are of a little higher hardness since the volume fractions of 15% over 10% Cap in a composition produced the highest values with a higher 20% particulate palm kernel shell combined with 50% coconut shell particulate in a tie.

It is clear that the relatively high values of the particulate palm kernel shell in the composite, coupled with the complimentary presence of coconut shell particules in the composite to assist in the confronting the shape variation as a result of the notching action of the hardness equipment on the composite. In addition, the composite that revealed the lowest value is a tie between (5PK, 20CSP), and (25CSP)% composites. The reason is because the volume fractions of palm kernel particulates are corresponding low as 5% and 0%, the low hardness composites. The samples in the formulation 2 categories have generally values of hardness with a mean of all the sample hardness as 22.73 HV. Still on Table 1, formulation 3 has the sample composite in terms of hardness. It is apparent that the larger presence of CSp in the epoxy matrix over that of the egg shell particles is responsible for the high hardness value of the (15PSp 110ESp)% composites periwinkle shell particles are naturally harder than egg shell particles which are known to cave in to shape change and deformation effects. The combined effect of these two particles in the (15PSp 10ESp)% composite produced the highest hardness value. The combined effect of these particles in the epoxy matrix produced good interfacial adhesion in the composite which withstands the notching effect of the on the shape change. However, the single effect of periwinkle shell in (2PSp)% epoxy composite produced the lowest performing composite in terms of hardness

In formulation 4 of Table 1, the peak hardness performance was obtained (100Pp, 15PSp)% epoxy composite. The protective function of periwinkle shell and its ability to survive coastal waters makes it characteristically stronger than orange peels. Thus, the superior hardness value of the (100Pp, 15PSp)% composite can be attributed to the larger presence of the periwinkle particles over the orange peel particles in the composite. The volume ratio of the particles produced a goal fibre matrix effect in the composite which helps to reduce the influence of shape change due to indentation giving the composite superior hardness values. Conversely, an increase of the volume ratio of orange peel particles in the (150Pp/10PSp)% composite ensured that the new composite obtained the least hardness value in the formulation 4 category.

The last formulation to be considered in Table 1 is the (PK/ESP) composites. In this category of composites, the (5PKSp/20ESP)% composite was found to obtain the highest hardness value of 26.5HV. This can be attributed to the combined volume fraction of both palm kernel shell and egg shell particles particulates of palm kernel shell and egg shell particles are known to have varying degrees of hardness. Thus, the value of the composite can be attributed to the combined volume fraction of the two hard materials in the epoxy matrix. This ensures that the composite exhibit good particle matrix interface which make it possible withstand shape change due to indentation and produce superior hardness values. Although particulate palm kernel shells are known to be harder than egg shell particulates. The larger volume fraction of the egg shell particulates in the particles makes up for its deficiency when compared with the palm kernel shell particles. The least performing hardness composite in terms of hardness is the (20PKSp/5ESp)%

The volume fraction of the particles in the composite is a reversal of that obtained by the best performing hardness composite.

Hardness outcome at 100 ^{0}C post-cored temperature

Table 2 describes the results obtained by the epoxy composite post-cured at 100^{o}C. For the formulation 1 composites, the (10 OPp/15CSp)% composite exhibited the best hardness performance with a hardness property of the coconut shell particles as well as its higher volume fraction in the epoxy matrix transcended the lower volume fraction and hardness of the orange particles in the composite. This unique blend of reinforcement particles ensured a good particle matrix interface and resistance to shape change by indentation that is necessary to obtain high hardness values. The resultant composite with the highest hardness results also bears strong correlation with the (5 OPp, 20CSp)% composite which gave the highest hardness values under the 50^{o}C post-cured composites. On the other hand, the (200Pp, 5CSp)% composite produced the least average hardness performance of 18.3. In Formulation/composites. Thus, the inferior hardness property of the orange peel particles and its higher volume fraction over that of the coconut shell particles is responsible for the lowest hardness value.

For formulation 2, composites in Table 2, the (5PKSp, 20CSp)% composite was found to obtain the highest hardness value of 25.6HV. Palm kernel shell and coconut shell particles are known to be typically hard and are found to compliment themselves in the (5PKSp, 20CSp)% composite. This volume fraction combination of the particles produced the peak hardness performance in the formulation 2 composites. A 5% increase and decrease in the volume fraction of palm kernel and coconut shell particles was seen to reduce the hardness slightly in the (10PKSp, 15CSp)% composite. Good particle matrix interface produced by combination of 5PKS$_p$ and 20CS$_p$)% in the composite is responsible for resisting the notching effect of the hardness equipment on the composite. The (25PSP)% composite exhibited the peak hardness performance in 100^{o}C post-cored Formulation 3 composites with a hardness value of 23.1HV. the combination of 25PSp and OPS$_p$ in the epoxy matrix was found to produce the best effect in the hardness of the formulation 3 composites.

The hardness of the periwinkle shell particles which makes the mollusk to survive in coastal waters was found to give the optimum hardness in the Formulation 3 composites. On the other hand, the (25 ESP)% composite obtained the least hardness value of 19.3HV in 100^{o}C post-cured formulation composites. The disparity in hardness values of the (25PSP)% and (25 ESP)% shows the superiority of the periwinkle shell particles in resisting shape change due to indentation over the egg shell particles which is more likely to cave in due to notching effect. For the formulation 4 composites made up of (OPp/PSp) composites, the peak hardness performance was again exhibited by the (25PSP)% composite. Typically like the Formulation 3 composites, the combined effect of different volume fractions of orange peel and periwinkle shell particles could not produce the optimum hardness in the Formulation 3 composites. Thus, the singular presence of the periwinkle shell particles in the epoxy matrix (25PSp)% produced the highest hardness property. The lowest hardness was exhibited by the (20 OPp/5 PSp) composite with a value of 15.9HV. This indicates that the larger volume ratio and the inferior hardness of orange peel particles surpassed the hardness effect offered by the 5% PSp in the epoxy composite. For the formulation 5 composites in Table 2, the best hardness performance was exhibited by the (5PKSp, 20ESp)% composites. The harder 5% palm kernel shell particles was by the softer 20% egg shell particles produce a hardness value of 26.9HV. on the other hand, 257 PKSp)% composite gave the smallest hardness value of 19.3. these hardness results demonstrates that particulates egg shell cannot produce the desired hardness values in the epoxy composite but can be used to compliment another particulate filler in producing the desired hardness effect.

Hardness outcome at 120^0C post-cored temperature

Table 3 describes the 120°C post-cured epoxy composites. For the formulation 1 composites made up of (OPp/CSp) described in Table3. The (25Pp)% composite was found to obtain the highest hardness value of 28.6HV over the composites having the combination of particulate orange peels and coconut shells as well as the (25 esp)% composite. Coconut shell particles are characteristically harder than orange peel particles as demonstrated in the 80 and 100°Cpost composites. However, the 120°Cpost-curing the (25OPP)% composite producing a superior hardness performance over the (25CSP)% composite. The least hardness performance was demonstrated by the (100Pp, 15CSp)% composite with a hardness of the orange peels and coconut shell particles could not produce the optimum hardness after 120°C post-curing treatments. The formulation 2 composites which comprise of (PKSp/CSp) are described in Table 2. The composite with the peak hardness performance was found to (25PKSp)% composite with a hardness value of 24.3HV. This demonstrate the superior hardness property of the palm kernel shell particles and the ability of the (25PKSp)% composite's hardness to be fully optimized at 120°C post-coring treatments. Although the combination of the hardness properties palm kernel and coconut shell in the epoxy composites was complimentary, it did not produce the peak hardness in the formulation 2 composite.

The composite with the minimal hardness was found to be (10PKSp, 15CSp)%. Thus, the 25% palm kernel shell particles produced the needed fibre matrix effect to resist shape change in the composite. For the formulation 3 composites, the highest harder performance was given by the (25 ESP)% composite. This formulation, the egg shell particles exhibited superior hardness under the 120°C post-coring regime. This was ensured by good interfacial adhesion between the epoxy matrix and 25% egg shell particles in the composite. Although, this was not achieved under the 80, and 100°C post-cored regimes, the peak hardness demonstrated by the (25 ESP)% composite indicates that the composite's hardness property was able to be optimized during the 120°C post-curing treatments. This produced strong interfacial adhesion necessary to resist the notching effect of the hardness equipment. The least hardness performance was demonstrated by the (15 PSp, 10ESp)% composite. For the formulation 4, composites which comprise of (OPp/PSp) described in Table 3, the peak hardness of 28.6 HV, the peak hardness of 28.6 HV was exhibited by the (25OPp)% composite. The addition of particulate orange peel particles in the (25 OPp)% and the ability of the composite's hardness to be optimized gave it a superior hardness value over other composites. The least hardness was observed in the (20 OPp/5CSp)% composite with a hardness value of 17.7 HV which Lastly, the formulation 5 composites which comprise of palm kernel shell and egg shell particles are described in Table 3. The (25ESP)% composite demonstrated the peak hardness performance with a value of 24.6HV. Over those of the other composites which comprise of palm kernel shell and egg shell particles as well as the (25PKSp)% composite. This indicates that the singular influence of the egg shell particles as well as the (25PKSp)% composite. This indicates that the singular influence of the egg shell particles in the epoxy matrix was enough to give the much needed hardness to the composite. The (25 ESP)% composite did not exhibit superior values when post-cured at 80 and 100°C. However at 120°C post curing temperature the hardness property was completed and fully optimized. This ensured resistance to shape change by indentation in the composites.

Average Hardness at different temperatures

The hardness property of a material is a measure of its ability to resist shape change by indentation. This characteristic has been found to be helpful in making the right choice in material selection, as well as in material evaluation and quality control in production processes. The hardness test was carried out on the selected polymer matrix composites on the hardness machine using a torque of 2942 Nm and a dwell time of 10 seconds (Fig. 3 to 7). The hardness tests was performed on the polymer composites on three data points while an average value was computed for each composite from the data points. For the Formulation 1 (OP_p/CS_p) composites, the ($25OP_p$) displayed a hardness of 16.7, 21.9 and 28.6 HV for the 80, 100 and 120 ^oC post-curing regimes, respectively. However, the introduction of the coconut shell particles under the different post-curing temperatures produced different hardness values in the composites. The (5OPp/20CSp)% exhibited the highest hardness of 21.3 HV under the 80 ^oC post-curing temperature treatment, while the ($10OP_p/15CS_p$)% composite obtained the peak hardness of 25.6 HV under 100 ^oC post-curing temperatures. Lastly, the (25OPp)% composite reached the highest hardness value of 28.6 HV under the 120 ^oC post-curing regime. The composites experienced different hardness values under different post-curing temperatures due to the effect of different post-curing regime on their particulate volume fraction.

For the Formulation 2 (PKSp/CSp) composites, it was observed that the 80 ^oCpost-curing regime resulted in the (10PKSp/15CSp) and (5PKSp/20CSp)% composites obtaining the a joint peak of 29.3 HV. After the 100 ^oC post-curing treatment, the (20PKSp/5CSp)% produced the highest hardness values of 26.7 HV, while the (25PKSp) composite obtained the highest hardness of 24.3 HV under the 120 ^oC post-curing temperature. For the Formulation 3(PSp/ESp) composites, the (25PSP)% experienced hardness values of 16.9, 23.1 and 22.1 HV under the 80, 100 and 120 ^oC post-curing temperatures.

The addition of the egg shell particles into the matrix changed the hardness of the composites as the post-curing temperature changed. The (15PSp,10ESp)% composite obtained the highest hardness of 24.5 HV, while the (25PSp)% composite obtained a peak hardness value of 23.1 HV. Finally, the (25ESp)% composite obtained the highest hardness value of 24.6 HV under the 120 ^oC post-curing regime. The (25OPp)% composite exhibited the highest hardness value of 28.6 HV under 120 ^oC in the Formulation 4 (OPp/PSp) composites category. This was followed by the (25PSP)% obtaining a peak hardness value of 23.1 HV from the 100^oC post-curing regime, while the (10OPp/15CSp)% composite recorded the topmost hardness of 24.6 HV under the 120 ^oC. For the Formulation 5 (PKSp/ESp) composites, the effect of the post-curing temperatures produced similar effect on each of the composites. The (5PKSp/20ESp)% composite obtained the highest values of 26.5 and 26.2 HV under the 80 and 120oC post-curing temperatures, while the (5PKSp/2ESp)% exhibited the highest hardness of 26.9 HV under the 100^oC post-curing regime. Overall, the (10PKSp,15CSp), (15PKSp,10ESp) and (5PKSp,20ESp)% composites exhibited the highest average hardness of 24.87, 25.07 and 25.27 HV across all the post-curing temperature regimes. This can be largely attributed to the different fibre volume of the reinforcement particles in each composite and their distinct behaviour during the post-curing process.

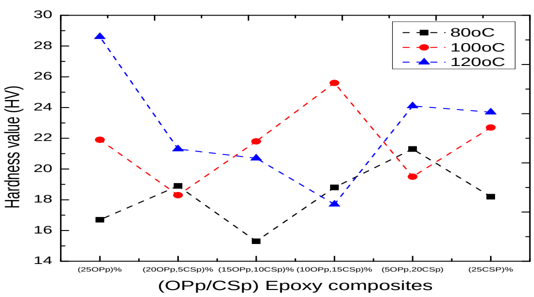


Fig. 3. Hardness values of (OPp/CSp) composites under different post curing temperatures

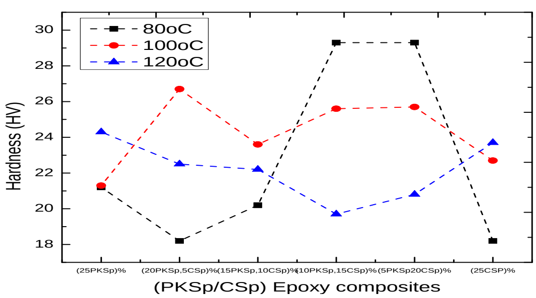


Fig. 4. Hardness values of (PKSp/CSp) composites under different post curing temperatures

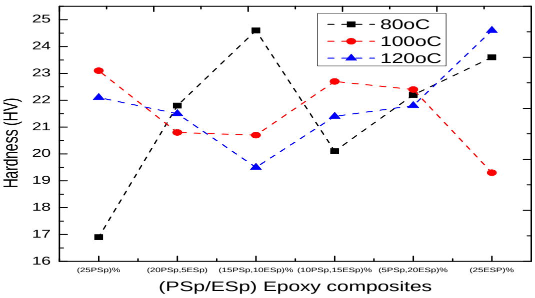


Fig. 5. Hardness values of (PSp/ESp) composites under different post curing temperatures

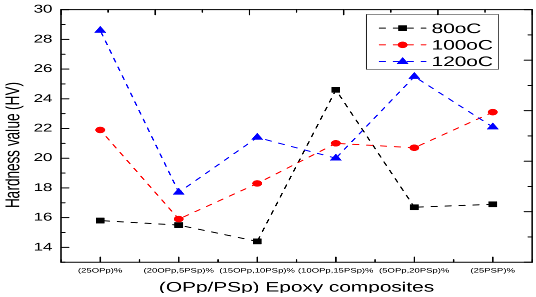


Fig. 6. Hardness values of (OPp/PSp) composites under different post curing temperatures

For the Formulation 1 (OPp/CSp) composites, the 80 ^{o}C cured composites obtained the lowest hardness values comparatively with the 100 and 120 ^{o}C cured composites. The 120 ^{o}C cured composites produced the highest hardness with the (25OPp) % composite giving a hardness value of 28.6 HV and the highest average of 22.4 HV. In the Formulation 2 (PKSp/CSp) composites, the 100^{o}C post-cured composites exhibited the highest hardness behaviour except for the 80 ^{o}C post cured (10PKSp/15CSp) and (5PKSp/20CSp)% composites which exhibited a hardness of 29.3 HV. The (5PKSp/20CSp)% composite has the largest average of 25.27 HV. In the Formulation 3 (PSp/ESp) category, there was no dominant influence of post-curing temperature on the hardness values of the composites. The (25ESp)% composite gave the highest hardness with an overall value of 22.5 HV. The 120 ^{o}C post-curing temperature produced a comparatively superior hardness behaviour in the Formulation 4 (OPp/PSp) composite category with the (25OPp)% composite having the highest hardness values. For the Formulation 5 (PKSp/ESp) composite category, the post-curing temperatures also produced different effects on the hardness of the composites with the (15PKSp/ESp) composite having the highest hardness value of 25.07 HV.

Overall, the (5PKSp/20CSp)% composite exhibited the optimal hardness behaviour across all temperatures with 29.3, 25.7 and 20.8 HV and highest average of 25.27 HV. The disparity in the hardness values obtained in the composites can be attributed to the different volume fraction of reinforcement particles in the epoxy matrix of the composites and their individual behaviour to the post curing temperatures. The high hardness values obtained in the (10PKSp,15CSp), (15PKSp,10CSp) and (5PKSp,20CSp)% composites may also be attributed to the hardness properties of palm kernel, coconut shell particles and their high volume fraction in the epoxy matrix of the composites.

In scientific investigations, it is often desired to compare the results obtained in the current research with those already documented in literature. Consequently, the outcome of this study are compared with that of Rana [49] that worked on the mechanical characteristics of Al_2 O_3-50Vol%ZrO_2composites and a second documentation by Kannan [50] that worked on friction welding of dissimilar linkages. Rana [49] obtained the utmost hardness of 14GPa for the composite considered (i.e. Al_2O_3-3V-ZrO_2) that was sintered at 1600^{0}C. Compared with the current research, there are disparities. First, the 14GPa hardness value is several multiples away from the two-digital HV value of the current study (i.e. extremely higher value). Second, the temperature of post-curing (i.e. 120°C) for the current samples and the sintered temperature of the reference sample is 1480°C (also multiples of the current research). It is suggestive that the specimens for the current study current withstand the impact of high temperature and high torque applications. Thus, for the brakepad that is proposed for the samples as an application route, the vehicle application may not be appropriate. However, lighter applications such as vehicle toys that do not require such elevated torque and temperature may be suitable. By comparing the current research with Kannan [50], the following emerges. Two ranges of hardness values were obtained. The first is for aluminum alloy side between 1350-1500 HV while the second is for stainless steel of around 150-300 HV. Even considering the lower range value of 150HV, this is almost 10times the value obtained, which confirms that the samples tested cannot withstand high impact applications but for the toy vehicle brake pads as suggested earlier.

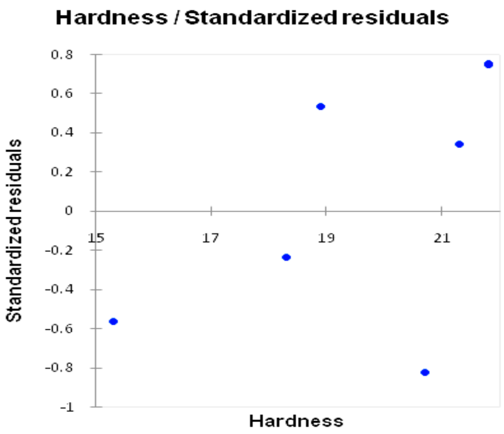
In this paper, arguments have been raised that single reinforcements is an old literature convention and that dual blends of reinforcements use in polymer composite with the evaluation of micro-hardness in mind is the new order-of-the-day in research. Through a rigorous experimentation that involves developing dog-bone shaped specimens, which were eventually used for hardness examination, the function of dual blends were analytically explained in analysis. The results of the experiments contribute a superior insight of hardness evaluation procedure and an enhance understanding of the interaction between hardness and the volume fraction of the reinforcement used in the composite development. In the current research a volume fraction ranging from 0 to 25% content of either of the reinforcements in dual blends is used. This therefore appends depths to the current research on hardness in polymer composite development. Second, through drawing from as well as combining the arguments arising from the recent accounts given by the composite reinforcement literature to provide an explanation on the manner in which hardness value evaluation gets infused into the dual mixing of composite reinforcements in polymer composite development, this research has heeded to the call, as provided in Ajibade et al. [48], to shed additional light on the fabrication of composites when the reinforcements are paired and mixed. The adopted standpoint in this research compliments documented studies in the metal matrix composite literature by focusing on particulate reinforcements instead of fibres and whiskers that previous scholars have primarily focused on. Nevertheless, the hardness value determination issue as well as the paired mixture of reinforcements for polymer composite development are possible to be intertwined. It is as well possibly mutually reinforcing. For example, using this approach, the cautious choice of volumetric ratios is triggered as choosing none percentage contribution of certain ratios is wasteful and not optionally motivated.

The approach presented showcases practical value for composite engineers and scientists as well as the composite companies and even the stakeholders interested in polymer composites. First, it provides a conscious effort art reducing the cost of composite development and the overall price tag on the manufactured composite. As a consequence, if the cost of the manufactured polymer composite is high, the organizational sales will be affected when eventually the composite is developed and in market. Also cost reduction of the sales of low cost, affordable composite promotes the manufacturing company’s goodwill. Specifically, the practical and theoretical structure presented in this research complements the methods that currently exist in literature. By revealing how the variations of the volume fractions of the reinforcements in the epoxy matrix responds to hardness variation, the frame work assist to detail the nature of relationship among the important variables of hardness, load, dwelling time and post-curving temperature of the specimens.

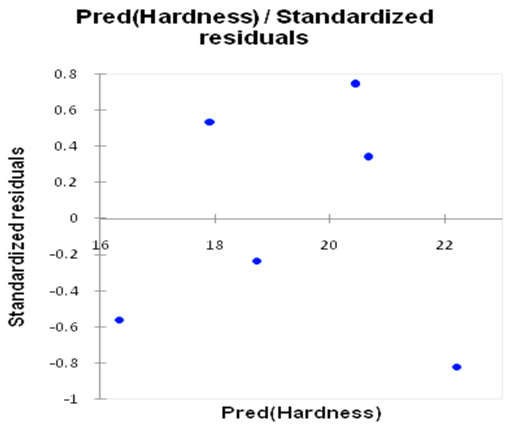
The mathematical relationship

$$Hd = -13.32 - 0.1Tn + 5.56Im - 0.043Fl \quad (1)$$
$$R^2 = 0.772$$

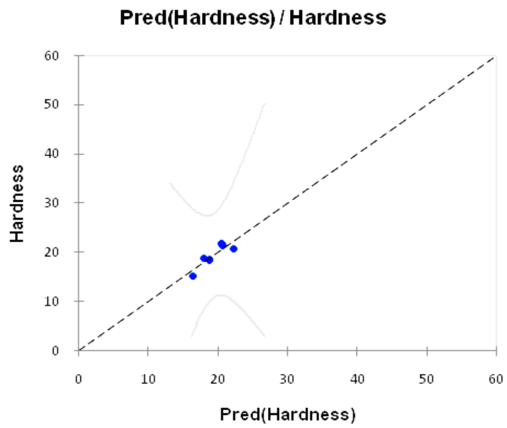
The association among the mechanical properties of the (OPp/CSp) composite was described with a model using the multiple regression analysis as shown in Equation (1). The hardness values of the composite were fitted as the dependent/response variable while the values of the tensile, impact and flexural properties were adjusted as the independent/predictor variables at six levels of observations. A confidence interval of 95 % and P value of < 0.05 were fixed for the model, while five degrees of freedom could be observed from the ANOVA table in Table 1. This indicates that five unique matrices were solved to predict the dependent variable. From the model, it can be observed that the impact values have the highest and only positive effect on the hardness of the composite. This implies that as the impact increases, the hardness improves while the negative values of the tensile and flexural strengths reduces the hardness. The accuracy of the model in describing the mechanical properties of the composite can be understood in terms of a high coefficient of determination (R^2) value of 0.772 which compares favorable with existing literature [51-52]. An R^2value of 0.772 denotes that 77.2 % of the response variable can be adequately explained by the model [53]. The remaining 22.8 % are regarded as residuals which represents the difference between the observed response and fitted response as described in Fig. 8 (a) and (b). The close clustering of the observations around the true regression line as shown in Fig. 8(c) indicates a high level of accuracy was achieved by the model in predicting the mechanical properties of the (OPp/CSp) composite.



(a)

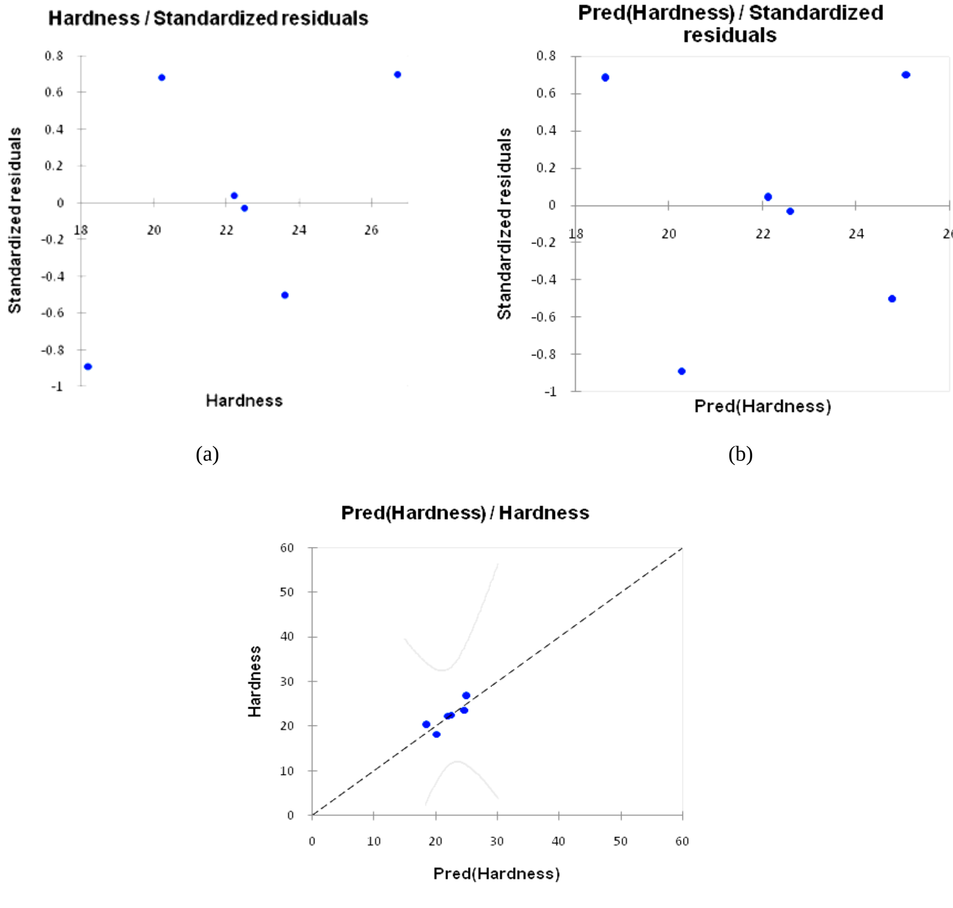


(b)



(c)

Fig. 8. (a) Residuals of experimental hardness (b) Residual of predicted hardness and (c) Correlation plots between experimental and predicted plots for hardness of (OPp/CSp) composite



(a) (b) (c)

Fig. 9. (a) Residuals of experimental hardness (b) Residual of predicted hardness and (c) Correlation plots between experimental and predicted plots for hardness of (PKSp/CSp) composite

$$Hd = 79.81 - 0.053Tn - 8.5Im + 0.043Fl \quad (2)$$
$$R^2 = 0.746$$

The mechanical properties of the (PKSp/CSp) composite has been modelled with the use of the multiple regression analysis as described by Equation (2). Using the hardness values as the dependent/predictor variable and the observations of the tensile, impact and flexural properties as independent/predictor variables at six measured levels, a confidence interval of 95 % and P < 0.05 were maintained in the build up to the model. Further, five degrees of freedom (DF) could be identified from the ANOVA table. This means that five unique matrices were solved to predict the response variable. From the above relation, it can be observed that the hardness of the composite increase with the flexural strength, while the tensile strength and impact have negative effect on the hardness of the composite. The correctness of the model in predicting the mechanical properties of the composite could be understood with a high coefficient f determination (R^2) which was derived as 0.746 which bears much correlation with the literature [51-52]. Thus, for the model described by Equation (2), an R^2 value of means that 74.6 % of the response variable can be sufficiently described by the model. The remaining 25.4 % can be accounted for as residuals which is the difference between the observed response and fitted response as described by Fig. 9 (a) and (b). The accuracy of the model in predicting the mechanical properties of the composite can be seen in Fig. 9(c), where some of the points falls exactly on the true regression line while others revolve closely around it.

$$Hd = 64.39 - 0.065Tn - 6Im - 0.039Fl \qquad R^2 = 0.895 \tag{3}$$

Equation (3) describes the association among the mechanical properties of the (PSp/ESp) composite which has been modelled with the multiple regression analysis technique. In this model, hardness values were fitted as the dependent/response variable while tensile, impact and flexural values were considered as the dependent/predictor variables at six levels of observations. A confidence level of 95 % and P <0.05 were used to build up the model while five degrees of freedom (DF) could be observed from the ANOVA table. This shows that five unique arrangements were contemplated to predict the response variable of the model. From the relationship described in Equation (3), the tensile, impact and flexural properties have negative effects on the hardness of the composite. The precision of the model in predicting the mechanical properties of the composite is measured in terms of a high coefficient of determination (R^2) of 0.895. The R^2value of 0.895 means that 89.5 % of the dependent variable can be satisfactorily explained by the model described by Equation (3). The outstanding 10.5 % can be seen as residuals in Fig. 10 (a) and (b) which represents the difference between the observed response and adjusted response. In Fig. (3c), the observations can be seen to fall directly on the true regression line which shows a high level of accuracy of the model in predicting the mechanical properties of the (PSp/ESp) composite.

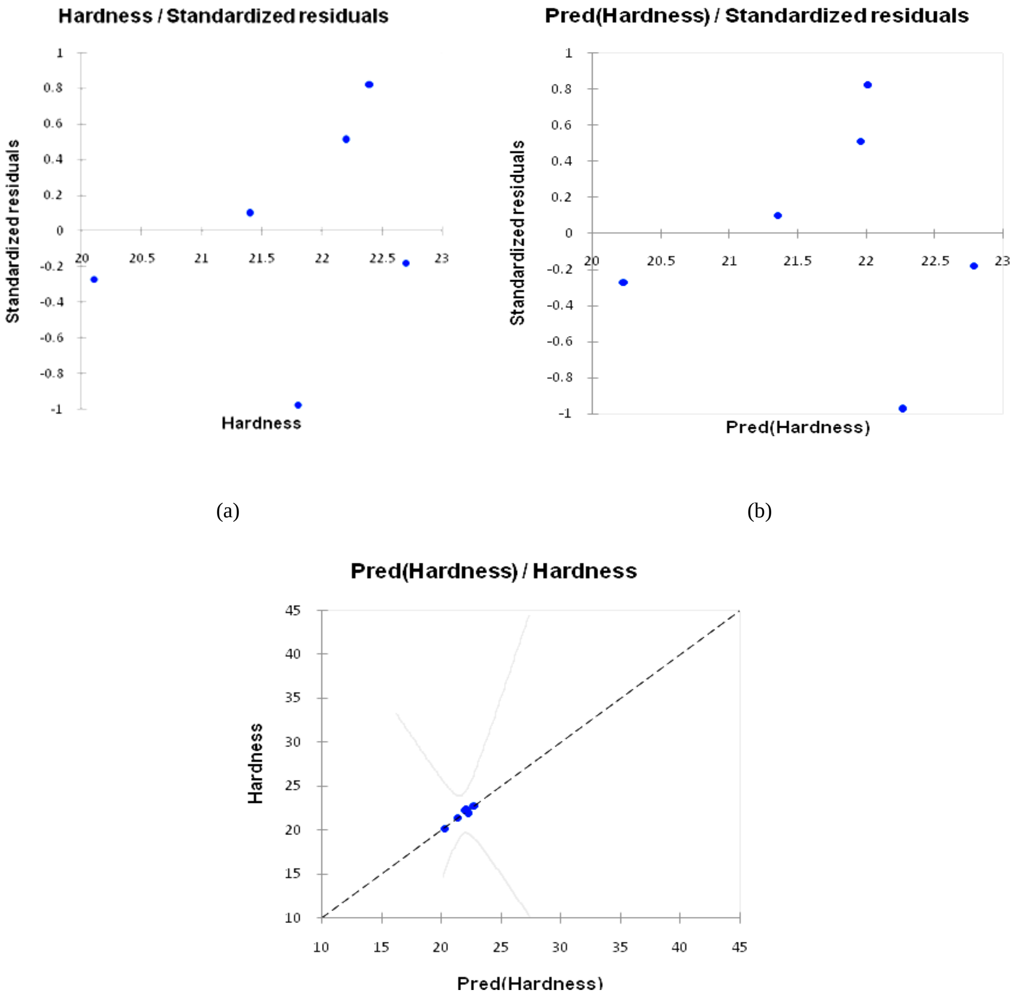
$$Hd = 79.81 - 0.053Tn - 8.5Im + 0.043Fl \qquad R^2 = 0.603 \tag{4}$$

The association among the mechanical properties of the (OP_p/PS_p) composite was modelled using the multiple regression analysis as described by Equation (4). In the build up to the model, the values of hardness were fitted as the dependent/response variable while tensile, impact and flexural values were adjusted as the independent/predictor variables at six levels of observations. Also, a confidence interval of 95 % and P < 0.05 were also fixed in the model development. Consequently, five unique matrices were contemplated from the five degrees of freedom of the ANOVA table in the prediction of the response variable. The model shows that only the flexural strength have positive coefficient. This implies that as the flexural strength increase the hardness of the composite is enhanced. The correctness of the model in predicting the mechanical properties of the (OPp/PSp) composite can be understood in terms of a high coefficient of determination (R^2) which was obtained as 60.3 %. Thus, an R^2 value of 0.603 means 60.3 % of the response variable can be explained by the model. The outstanding 39.7 % can be accounted for as residuals which represents the difference between the observed and fitted response as described by Fig. 11 (a) and (b). Further, the clustering of the observations around the true regression line in Fig. 11 (c) shows a high level of accuracy of the model in predicting the mechanical properties of the (OPp/PSp) composite.

A model describing the association among the mechanical properties of the (PKSp/ESp) composite was developed with the aid of multiple regression analysis. The hardness of the composite was fitted as the dependent/response variable while the tensile, impact and flexural values were adjusted as the independent/predictor variables in the development of thee model at six levels of observations. A confidence interval of 95 % and P < 0.05 were fixed in the build up to the model. Five degrees of freedom (DF) were observed from the ANOVA table in Table 1. In other words, five matrices were resolved in the prediction of the response variable. The impact and tensile strength of the composite can be seen to have a positive coefficient in the model described by

Equation (5). This indicates they influence the hardness of the composite positively with the impact property having a greater influence due to its high positive coefficient. The accuracy of the regression model was checked with a high coefficient of determination (R^2) value which was derived as 0.972. The high R^2 of 0.972 indicates that 97.2 % of the dependent variable can be sufficiently accounted for by the model. The remaining 2.8 % are described in Fig. 12 (a) and (b) as residuals which correspond to the difference between the observed and fitted response values. The observations of the model can be seen to lie accurately on the true regression line in Fig. 12 (c) showing a high level of correctness of the model in predicting the mechanical properties of the composite.

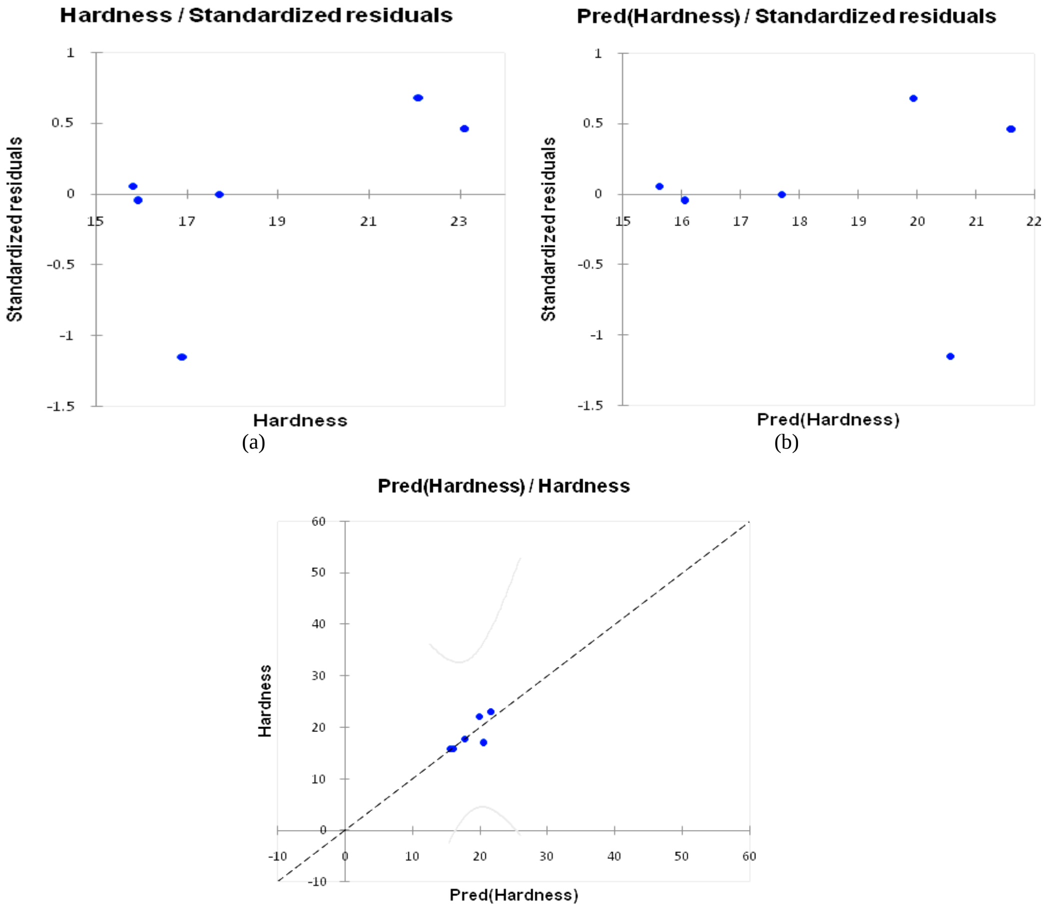
$$Hd = -39.53 + 0.11Tn + 8.99Im - 0.088Fl \quad R^2 = 0.972 \tag{5}$$



(a) (b)

(c)

Fig. 10. (a) Residuals of experimental hardness (b) Residual of predicted hardness and (c) Correlation plots between experimental and predicted plots for hardness of (PSp/ESp) composite



(c)

Fig. 11. (a) Residuals of experimental hardness (b) Residual of predicted hardness and (c) Correlation plots between experimental and predicted plots for hardness of (OPp/PSp) composite

Contributions to knowledge

Researchers have built inspiring strides in drawing attention to the probable developmental approach of obtaining effectively hard materials that attain the expected standards of the applications desired in composite structures and systems (e.g. [4, 5, 8]. However, studies that utilize agro-rooted fortifiers to develop polymer composites have till date congregated principally on a single fortified composite platform. A growing literature that accounts for this was made, for instance, as orange peels composites [9], coconut shells composite [12-14] and egg shells composite [20-21]. Although this string of investigations have served the significant goal of directing research attention to the delopment of lightweight and cheap composites for standard usage, it supposes that elevated hardness valued composites could be obtained from the perspective of a single dimension of fortifier. Importantly, as Ajibade et al. [48] revealed, for agro-based fortifiers involving coconut shells and orange peels, the perticulate forms performs exceptionally better in terms of material property enhancement, demonstrated in outstanding absorption performance of the fortifiers. Drwaing on the results and insight provided by Ajibade et al. [48] and other researchers, this study has built up an experimental procedure thatb attempts to account for the useful interfaces that characterise the use of dual blended fortified polymeric composite, for hardness enhancements, chosen from paired blending of particulate orange peels, coconut shells, periwinkle shells, egg shells and palm kernel shells.

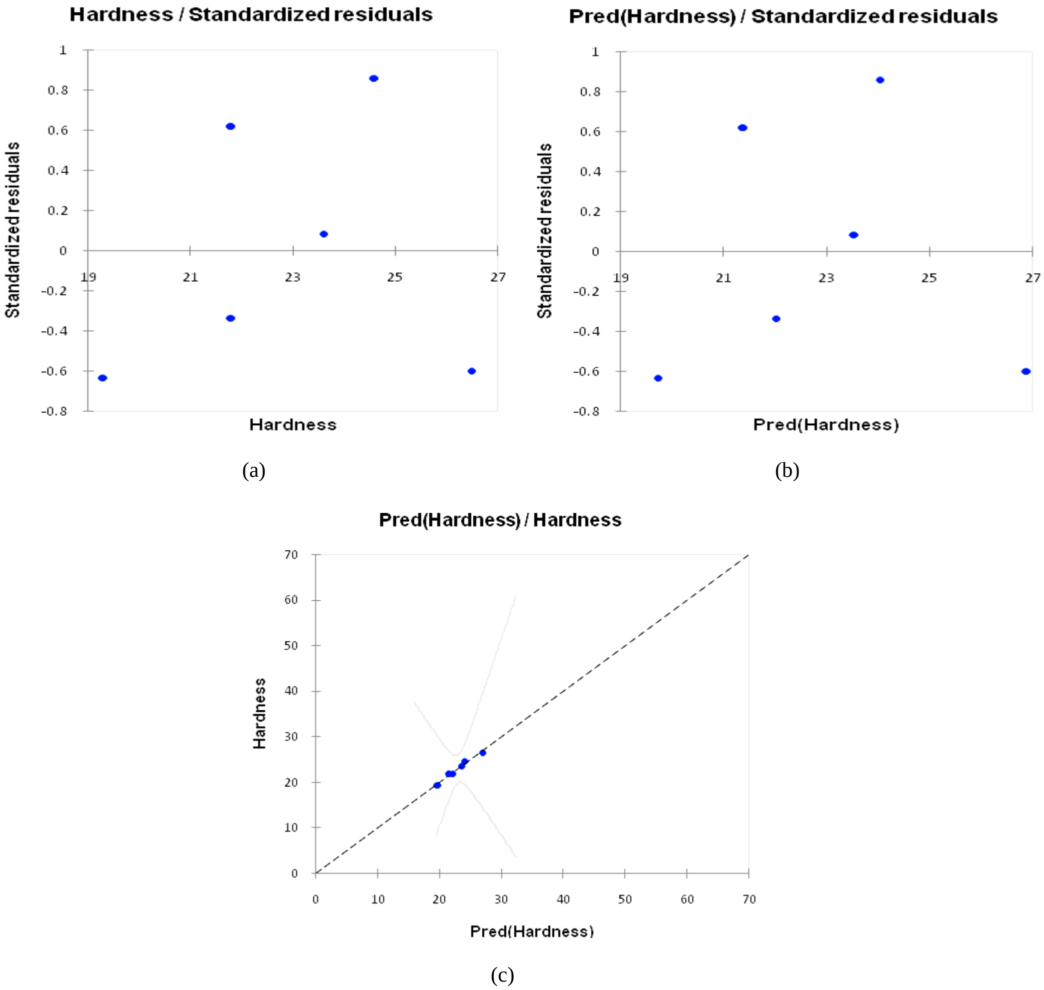


Fig. 12. (a) Residuals of experimental hardness (b) Residual of predicted hardness and (c) Correlation plots between experimental and predicted plots for hardness of (PKSp/ESp) composite

First, this research has demonstrated that combining two agro-rooted fortifiers, for instance orange peels and coconut shells in particulate form produces superior hardness values to the use of orange particulate alone in polymeric composites. Consider the literature data provided by Aighodion [9] in which a polyethylene composite of orange peel fortifier was developed and the hardness, for example, ranged from 2.83 HBR (approximately 2.98 HV) to 13.93 HRB (approximately 14.663 HV). By experimenting on the formulation of orange peels and coconut shells in a dual mixture of polymer composite and then obtaining the set of at least, middle and highest hardness values, the corresponding values of 15.3 HV to 25.6 HV. The obtained results in the current experiment exceeds Aigbodion et al.'s [9] results by over 400 % increase for the least value and over 74.5% increase for the highest value. This claims the superiority of the curresnt research over Aigbodion et al.'s [9] outcomes from the perspective of hardness. Thus, the current approach is new and significant and would benefit the composite community. Consequently, the experimental structure brings up certain impending queries regarding the nature of interactions between these fortifiers and how they could further enahnce in performance with respect to hardness evaluation. Second, a journey throough post-curing process of the developed composites has begun to exemplify how raising the temperature at post curing activities could substantially enhance the performance of the developed composites in terms of hardness value enhancement. Specifically, the experimental structure reveals how transition from the first degree post-curing (i.e. 80^0C), in this case, could produce a different result at an elevated temperature of 100^0C and still a better hardness results as 120^0C. This suggests that a progressive temperature elevation at post-curing of the polymer composite till a certain optimum threshold is reached is possible.

Conclusion

The following can be deduced from the hardness test results and are highlighted as follows:

- The average hardness of the composites increased across the post-cured temperatures
- Characteristically hard particles like coconut, palm kernel and periwinkle shell particles influenced the hardness of the composites where they were being employed
- The volume fractions of the reinforcement particles play a significant role in increasing or decreasing the hardness of the composites.

The experimental framework and the approach presented in the current research opens up opportunities for investigators to exploit a range of results even outside the polymer composite development domain. For instance, hardness value determination could be explored for dissimilar materials such that relationship analysis is explored among the varying parameters of changing speed, the pressure at forging as well as composition of carbon while other factors could be regulated. The procedure could also be extended to be novel methodology of tube-to-tube plate friction welding procedures while an exterior implement is applied. For the regression work, each model showed good significance and high correlation (R^2) values with the (PKS_p/ES_p) model obtaining the highest R^2 of 0.972. The models helped to understand which of the predictor variables was most relevant to the hardness response variable of the composite which will help to make informed decisions on practical usage.

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