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STUDY ON THE MECHANICAL AND DYNAMIC PERFORMANCE OF RECYCLED LDPE FILLED UNSATURATED POLYESTER COMPOSITE

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Abstract: Unsaturated polyester resin (UPR) is widely used as matrix in composite development; however, it has poor toughness property. To solve this problem, many researchers have used different tougheners to modify the resin, but the use of recycled low-density polyethylene (RLDPE) has not been explored. This work is aimed at modifying unsaturated polyester resin (UPR) with recycled low-density polyethylene (RLDPE) as a toughener and establishing the effects on the mechanical and dynamic mechanical performance of the RLDPE-filled polyester composite. Unsaturated polyester resin was modified with 1.18 mm RLDPE at different proportions of 1-4 wt%. Casting method was used for the production and the mechanical and dynamic mechanical analyses of the produced composite materials were carried out using ASTM standards. UPR modified with 1.5 wt% RLDPE exhibited the best impact than the un-modified UPR. The control (un-modified) sample had the highest flexural and tensile strength of 18 MPa and 14.02 MPa respectively which was about 26% and 25% higher than UPR modified with 1 wt% RLDPE. The Dynamic Mechanical Analysis (DMA) result showed that the composite does not depend strongly on the modifier loading as no regular pattern was observed for storage modulus, loss modulus and damping factor respectively.

Keywords: Composite, Unsaturated Polyester Resin, Recycled Low-density Polyethylene, Mechanical Properties, And Dynamic Mechanical Analysis.

1. INTRODUCTION

Unsaturated polyester resin (UPR) is a thermosetting polymer formed from the polymerization of a dibasic acid with a polyhydric alcohol. It is undoubtedly one of the widely used thermosetting polymers for composite development. Owing to its excellent dimensional stability as well as less expensive a lot of work has been reported on UPR composite [1-5]. These properties have made them the most preferred choice of matrices for composite applications however, the resin has low toughness property and hence, very brittle [4]**.** The brittle nature of UPR is considered a weakness inherent in the resin and this has limited it application in areas where high impact strength is required. Therefore, there is a critical need to modify the resin with a toughener to address this underlining problem and by extension broaden its area of applications.

Modification of existing polymers is so far the cheapest way of improving their properties than getting newly synthesized ones [6]. Over the years, a lot of additives, fillers and polymers of different types have been used to modify the properties of UPR. Dioctyl phthalate (DOP) was used as a modifier to enhance the impact strength of UPR to about 48 % as reported by Isa *et al*. [6]. 2-5 parts by weight of Polyvinyl chloride was also used as a polymeric modifier to influence the structuring of UPR by improving it surface hardness and bounding strength [5]. Epoxy resin and TiO_2 has being used for the modification of UPR properties and a progressive increase in the hardness, compression and impact strength was recorded as filler loading increased from 1 wt% to 3 wt% [1]. In addition, it was found that the addition of elastomeric additives as tougheners is one of the frequently used methods for improving the toughness property of brittle thermosets like UPR. However, this method reduces both the strength and glass transition temperature T_g respectively [4]. Finally, a lot of work has been done on the use of natural fibres as reinforcing filler for UPR composite in a bid to improve toughness property amongst other properties [2], [3], [7], [8] and [9].

In all these, no study has reported the use of recycled low-density polyethylene (RLDPE) as a toughener for the modification of UPR. RLDPE commonly referred to as 'pure water sachet' in Nigeria is the most common plastic waste released daily in Nigeria [10], [11] and has become a nuisance in every state and community in the country. Population growth and poor degradability of these water sachets has made them accumulate over time thereby resulting to an environmental eyesore and a threat to both man and aquatic lives [11], [12], [13]. Therefore, putting them to good use by solving an existing engineering problem for little to nothing is always a welcomed idea.

The aim of this work is to take advantage of the toughness property inherent in recycled low-density polyethylene (RLDPE) to serve as a toughener for UPR thereby lowering it brittle nature. The mechanical and dynamic mechanical performances of the resulting composite were also analysed.

2. MATERIALS AND METHODS

2.1 Materials

Reagents like UPR resin, Methyl-ethyl-ketone-peroxides (MEKP), and Cobalt were obtained from Olasco chemical store in Zaria, Nigeria. A metal mould and mould release agent were gotten from Recycling workshop, Nigerian Institute of Leather and Science Technology (NILEST), Zaria. Lastly, the pure water sachets (RLDPE) were gotten from different sachet water vendors and some were randomly collected from homes of end users and the environment, which includes dumpsites and drainages.

2.2 Preparation Methods

The water sachets were cut open with the aid of a scissors and washed thoroughly with water and detergent to remove dirt and grease after which it was rinsed severally with clean water until the water ran clear and no longer foamy. The wet sachets were air dried until it was no longer wet ready to be size reduced. The dried sachets were then shredded multiple times with the help of a plastic shredder for easy grinding. The shredded sachets were grinded and sieved into smaller particle size of 1.18 mm ready to be used as a toughener for UPR.

To formulate UPR/RLDPE composite, the unsaturated polyester resin (UPR) was mixed with the particulate RLDPE in different loading of 1 – 4 wt% at 0.5 wt% interval. A neat sample without toughener was also produced. Polyester mix was prepared by weighing 130 g of general-purpose unsaturated polyester resin into a plastic bowl and was mixed with 1 wt% catalyst (MEKP) for about 5 minutes. 1 wt% of RLDPE of the polyester weight was added to the mixture and mixed for 15 min after which 1 wt% cobalt accelerator was added and mixed for another 5 to 7 min or until the mixture begins to gel. The mixture was poured into a lined and greased metal mould where it was allowed to cure under pressure for a period of 24 hours and then post cured at 60 °C for another 3 hrs in an oven. The cured composite samples were cut to specifications and characterized for mechanical and dynamic mechanical properties.

3. RESULTS AND DISCUSSION

Important mechanical and dynamic mechanical properties such as impact, hardness, tensile, flexural, storage modulus, loss modulus, damping factor and glass transition temperature of the modified UPR were analysed.

3.1 Mechanical Characterization

Mechanical characterization is very crucial when analysing the performance and end use application of an engineering material in terms of strength, stiffness and toughness [14].

3.1.1 Impact properties

The impact test was conducted with the aid of a Charpy v-notch impact-testing machine with model Cat.Nr.412 and capacity of 15 J. Three samples were cut each for all eight formulations according to the machine specification; each sample was notched at 40^{o} at a depth of 2 mm across the longer part of the specimen. The specimen was then placed vertically facing the hammer, which was then released at an angle of 90^{o} to strike the sample, and the machine from which the impact strength was calculated generated the impact energy automatically. Figure 1 shows the effect of modification of UPR using RLDPE on the impact strength of the composite.

Figure 1 shows the impact result of the composite material produced. There was an increase in impact strength from 21.67 J/m to 37.5 J/m as RLDPE loading increased from 0 wt% to 1.5 wt%. However, further increase of modifier loading led to a continuous decrease in impact strength of the composite. The decrease in the impact strength may be attributed to the poor wetting and dispersion of the modifier (RLDPE) within the matrix phase due to higher loading resulting in the formation of voids and cracks within the composite thereby making the composite vulnerable to impact force.

Same trend was observed when unsaturated polyester (UPR) was modified using dioctyl phthalate (DOP) as a modifier as reported by Isa *et al*. [6]. 1.5 wt% RLDPE loading gave the maximum impact strength of 37.5 J/m which was about 73 % higher than the impact strength of the control sample with 0 wt% RLDPE loading. The ability of the composite produced to resist sudden force before deformation occurred proves that there was an improvement in the impact strength of UPR because of the influence of the toughener (RLDPE). This was very evident when compared to the neat sample, which is an untoughened UPR. This result has proved that RLDPE can act as a toughner for UPR.

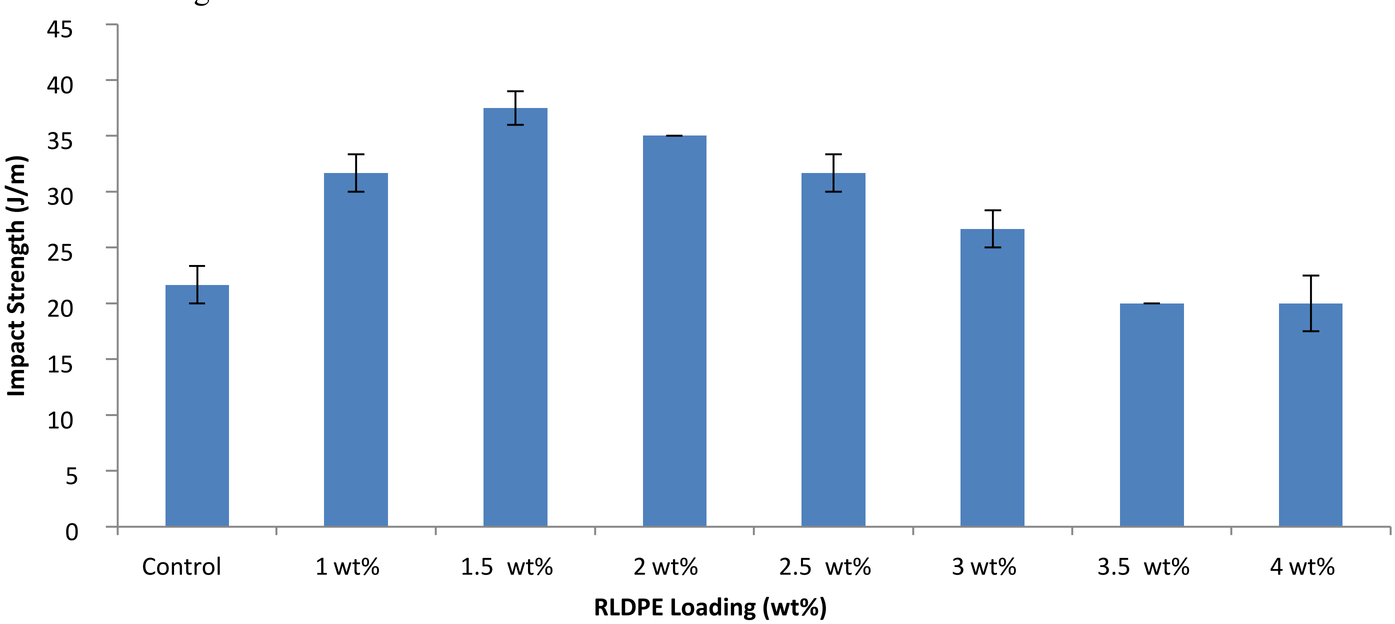
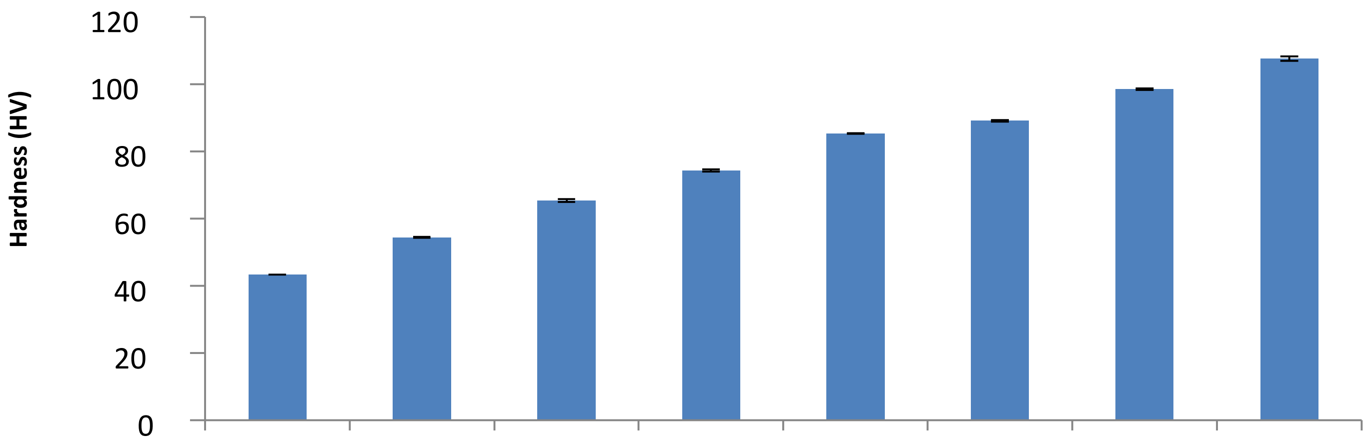


Figure 1: Effect of RLDPE on the impact strength of UPR composite

3.1.2 Hardness properties

The hardness test was performed via a Vickers hardness-testing machine. The composite underwent surface indentation on three different points to ascertain it ability to resist deformation by penetration from a harder material. The machine in HV generated the hardness result. Figure 2 shows the effect of modification of UPR using RLDPE on the hardness property of the composite.



Control 1wt% 1.5wt% 2wt% 2.5wt% 3wt% 3.5wt% 4wt%

RLDPE Loading

Figure 2: Effect of RLDPE on the hardness property of UPR composite

The produced composite showed a progressive increase in the hardness property of the composite as toughener (RLDPE) loading increased from 1- 4 wt%. Composite sample with 4 wt% loading gave the maximum hardness of 107.67 HV which is over a 100 % increase in hardness as compared to the untoughened UPR composite. Same trend was observed when unsaturated polyester was modified with carbonized and uncarbonized eggshell particles as reported by Hassan *et al*. [15].

3.1.3 Tensile strength

The tensile test was conducted with the aid of an electronic universal testing machine with model WDW-100 kN, model number 190536 and a maximum speed of 50 mm/min. Each sample was placed vertically in the wedge grip where it is allowed to undergo tension. The machine automatically generated the tensile strength. Figure 3 shows the effect of RLDPE on the tensile strength of UPR composite.

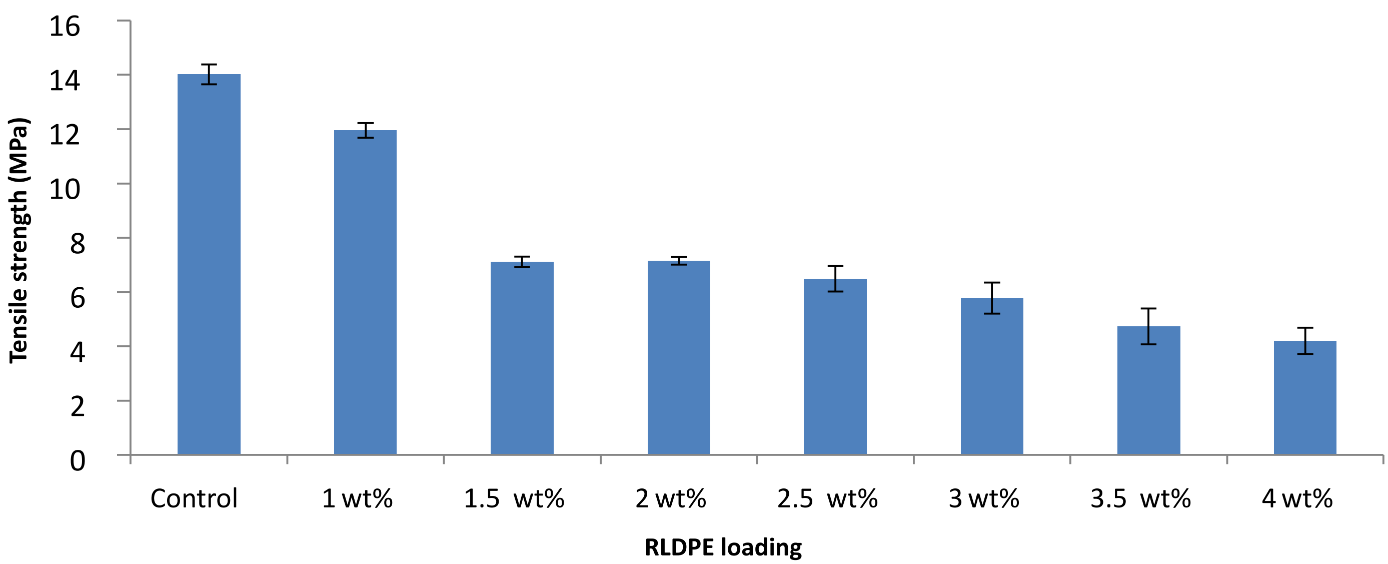


Figure 3: Effect of RLDPE on the tensile property of UPR composite

From the results, the control sample gave the highest tensile strength of 14.02 MPa while the tensile strength of composite samples decreased further as loading of the toughener (RLDPE) increases from 1 – 4 wt%. As a result, sample with 1 wt% RLDPE loading gave the maximum tensile strength of 11.95 MPa while sample with 4 wt% RLDPE loading gave the least tensile strength of 4.2 Mpa for the modified samples. The decrease in tensile strength with increase in loading of the toughener can be attributed to lack of interfacial adhesion between the matrix (UPR) and the modifier (RLDPE) due to phase difference. Therefore, the higher the modifier loading the weaker the adhesive force that exists between the matrix and modifier and hence a decrease in the tensile strength. The same trend was also observed when a plasticizer was used as a modifier for UPR.

3.1.4 Flexural strength

The ability of the composite material to withstand bending force was tested using the three-point bending method with the aid of a universal material testing machine (Enerpac) model Cat. Nr.261-100 kN capacity. Samples were cut out, each sample was placed horizontally on two stationed support pins with a gauge length of 80 mm, and a direct load was applied in the middle of the sample until it fails. The load required for the failure of the material was recorded from which the flexural strength was calculated. Figure 4 shows the effect of RLDPE loading on the flexural strength of UPR composite.

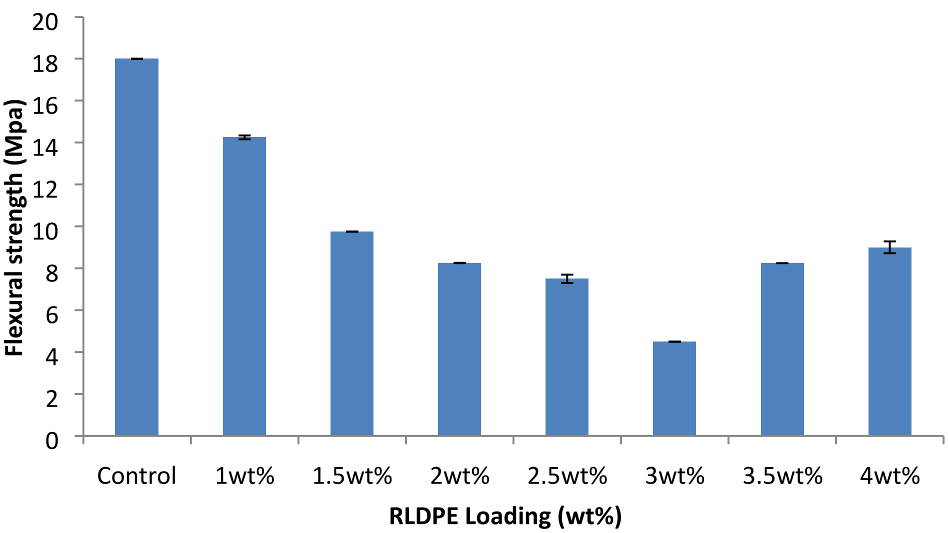


Figure 4: Effect of RLDPE on the flexural property of UPR composite

The composite showed a decrease in it flexural strength as loading of toughener (RLDPE) increases from 0-3 wt% and a sudden increase was observed at 3.5 wt% to 4 wt%. The control (untoughened) sample had the maximum flexural strength of 18 MPa and was followed by sample modified with 1 wt% RLDPE loading with a flexural strength of 14.25 MPa and decreased further until a flexural strength of 4.5 MPa was reached at 3 wt% before it increased again. The sudden rise in the flexural strength at 3.5 wt% - 4 wt% loading can be attributed to the increase in stiffness of the composite with higher loading of the particulate toughener. Same trend was observed when UPR was modified with varying loadings of carbon [16].

3.2 Dynamic Mechanical Analysis (DMA)

Dynamic mechanical analysis is an analytical technique used to determine the viscoelastic property of a polymeric material [17]. The samples were analysed with the aid of a dynamic mechanical and thermal analyser model NETZSCH DMA 242, temperature range of 20 – 150 ºC and frequency range of 0.25, 1.00 and 2.50 Hz. The Samples were prepared according to machine specification and was subjected to continuous oscillating load at an elevated temperature until it fails. The machine generated three results; these include the storage modulus (E^I), loss modulus (E^{II}) and damping factor (Tan δ).

3.2.1 Storage Modulus

Storage modulus refers to the amount of maximum energy stored by a material during one cycle of oscillation [18], [19]. The ability of the composite material to store energy with increase in temperature was analysed and the result is shown in Figure 5**.**

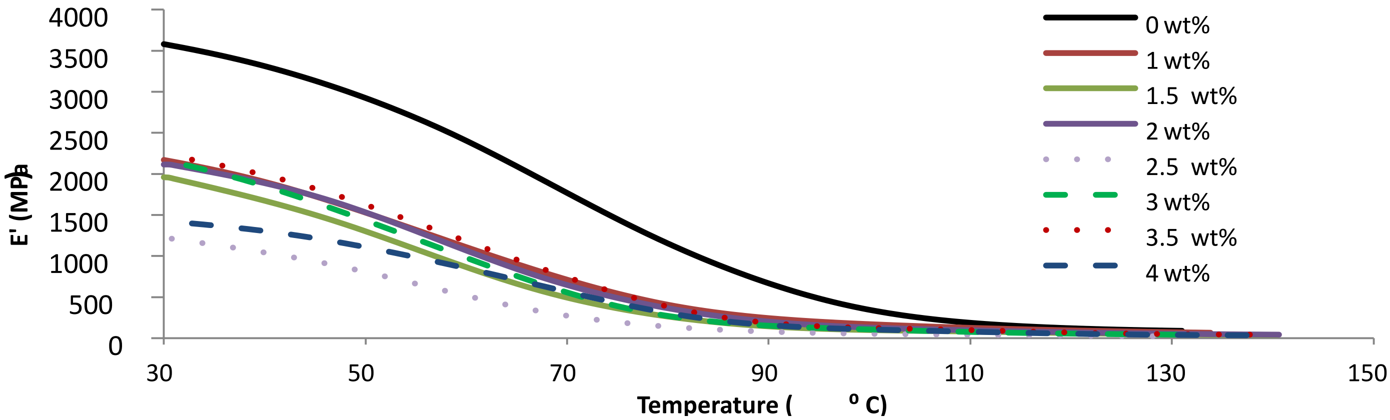


Figure 5: Effect of temperature on storage modulus of toughened UPR

From the result, it shows that the storage modulus (elastic response) does not depend strongly on the filler (RLDPE) loading as no regular pattern was observed. However, there was an obvious decrease in storage modulus for all the composite samples as temperature increases, and this is as a result of molecular mobility of the polymer chain [3], [20], [21]**.**

The control sample (untoughened UPR) recorded the highest storage modulus of 3569 MPa and followed by UPR sample toughened with 3.5 wt% RLDPE with a percentage difference of 64.17 %. A similar trend in storage modulus was observed when polyester was reinforced with sawdust, where it was reported that the control sample showed a higher storage modulus followed by sample modified with 10 wt% sawdust as reported by [3].

This implies that UPR sample modified with 3.5 wt% would perform better in a high temperature environment compared to other samples. This behaviour could be attributed to strong filler/matrix interaction [3], [18]**.**

3.2.2 Loss Modulus

Loss modulus is the amount of energy dissipated in form of heat by materials during one cycle of sinusoidal load [18], [19]. Figure 6 shows the viscous response of the toughened UPR at different temperatures. From the result, the loss modulus does not depend strongly on the loading of the toughener as no regular pattern was observed which is very similar to that of the storage modulus.

Again, control sample recorded the highest loss modulus of 249.45 MPa and was followed closely by sample modified with 3.5 wt% RLDPE loading with a percentage difference of 1.89 %. This implies that the control sample has the tendency to loss more energy compared to other samples and this could be due to the absence of filler.

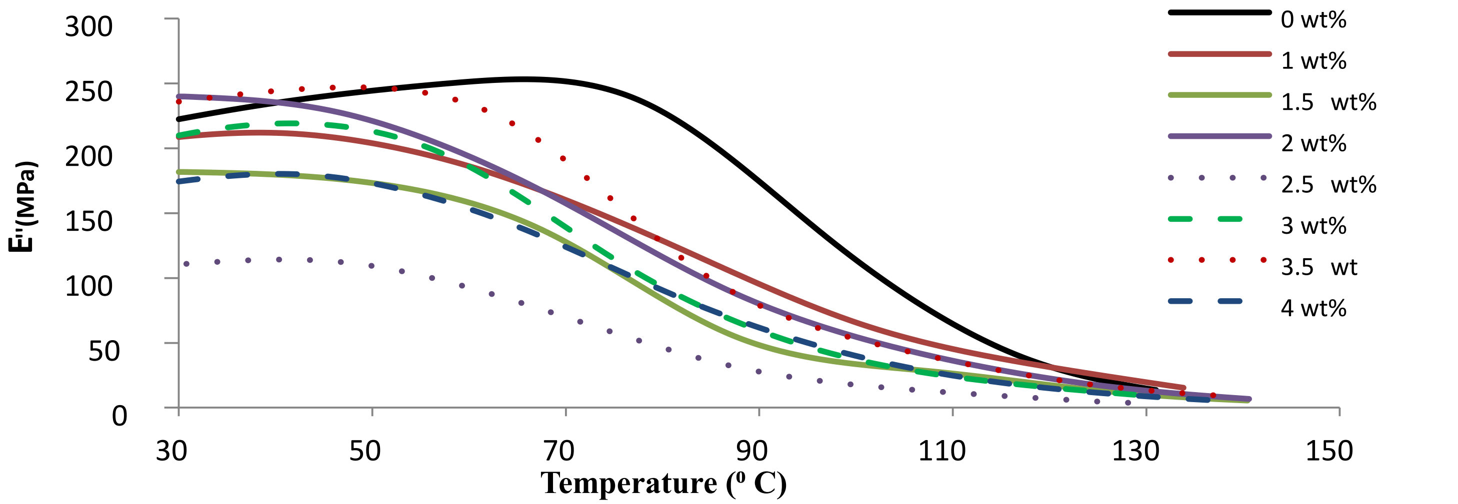


Figure 6: Effect of temperature on Loss Modulus of toughened UPR

3.2.3 Damping factor

Damping factor also referred to as tan delta (tan δ) is the ratio of loss modulus (viscous response) to storage modulus (elastic response) [18], [22] and gives the glass transition temperature (T_g) at its peak [20]. Figure 7 represents the damping factor of the composite produced.

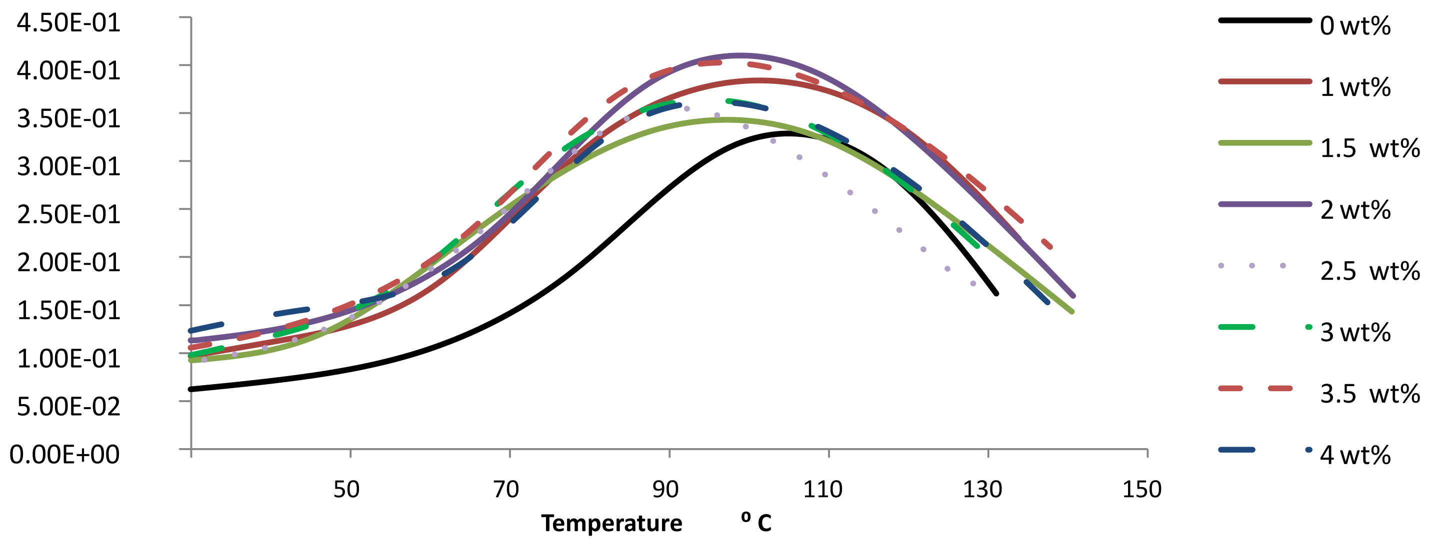


Figure 7: Effect of temperature on the damping factor of UPR

From the result, sample with 2 wt% loading gave the highest damping factor of 0.409 which is about 18.51 % higher than the control sample with a damping factor of 0.3451. This shows that sample with 2 wt% loading has a relative amount of energy dissipated when compared to the other samples [23]. UPR toughened with 1 wt% RLDPE loading gave the highest T_g of 104.3 °C and would perform better in a high temperature environment than the other samples.

4. CONCLUSION

Unsaturated polyester resin was successfully modified with low-density polyethylene (RLDPE) as a toughener. Although the composite produced responded poorly in terms of tensile and flexural strength, the impact and hardness property were largely improved over the untoughened UPR to about 73 % and over 100 % respectively. This finding, has however proved that RLDPE can be used as a cheap substitute for toughener in the production of UPR composites especially for applications where hardness and impact is of uttermost importance.

The DMA result shows that the composite does not depend strongly on the filler (modifier) loading as no regular pattern was observed for storage modulus, loss modulus and damping factor. However, the control sample gave the highest storage and loss modulus while sample with 2 wt% and 1 wt% RLDPE loading gave the highest damping factor and glass transition temperature (Tg) respectively.

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