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Identification of mechanical properties of an araldite LY556 blended with DNR composite and poly-acetal: A comparative study for sustainable future

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ABSTRACT

Epoxy material being a key in a wide range of applications has become a center of attraction for interdisciplinary research. However, the limitations so far reported in using this material has led to the development of some new pitches such as Polyacetal and Araldite. Polyacetal being currently employed in bushes, wipers, gears, etc. while Araldite composites with a potential of delivering some august properties can be an alternative approach to the former. In this work, a comparative study is carried out on the mechanical attributes of Polyacetal and Araldite (Epoxy) material. Various ASTM standard specimens casted with these materials are subjected to some exploratory assessments such as Tensile Test, Izod Impact Test, Charpy Impact Test, Three-point Bending Test and Vicker's Hardness Test in order to determine the respective properties.

1. Introduction

Polymers, used as an alternative to traditional materials such as steel, iron, etc. finds its profound use in aerospace and automobiles. Various types of polymers such as Polyacetal belonging to a group of thermoplastics, are widely used in range of applications such as gears in photocopying machines, screws in small toys, handles and so on. However, there are some drawbacks in these materials, that can be countered by further research and developments in the field. One such development is a class of Araldite (Epoxy Resin) belonging to thermosetting clan. It delivers some of the finest properties such as toughness, corrosive resistance, electrical resistance, temperature resistance, smoothness, durability, excellent flexibility, high reactivity and so on. These resins, when exposed to amines and anhydrides tend to deliver similar properties compared to its peers and when reinforced with natural fibers, produces lower density that gives an edge in lightweight applications (Morino, 2021; Saba et al., 2016). On addition of certain fillers such as copper slag, wheat husk and rye husk the physical strength and temperature resistance can be improved considerably (Biswas et al., 2010; Ren et al., 2019). Epoxy when partnered with MoS2 can deliver better elasticity and when reinforced with graphite and PTFE delivers better wear resistance (Huang et al., 2021; Liu et al., 2021a). But the surface developed in all the above cases is rough. This can however be smoothened by adding KH500 material (Liu et al., 2021b). In the circumstances discussed, only a particular property of the material at a time is improved. Araldite has a characteristic of delivering some astonishing properties when mixed with materials such as ZrO2, TiO2, SiO2, GO and so on (Lu et al., 2005; Nayak et al., 2014; Bogdanova et al., 2020). This quality makes it an evolutionary material whose combinations and types can be explored in retaining the properties sustainably (Suresh Kumar & Sanjeevamurthy, 2021; Zhang et al., 2021). One such exploration can be briefed by identifying a class of DGEBA resin belonging to Epoxy family (Parashar & Narula, 2015; Alessi et al., 2015). Resin made of di-glycidyl ethers blended with bisphenol-A (DGEBA) are high degree cross-linkage mixtures and are generally used in glues, coatings, composites, printed circuits and so on (Parashar & Narula, 2015; Alessi et al., 2015). This high degree cross-linkage property

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makes it a brittle composite. However, Araldite LY 556, one of the latest upshots of this class of resin is used in countering the brittle nature and increasing toughness and that can be proved to be an alternative to Polyacetal based composites. In this work, an elementary study is carried out on Araldite LY 556 (Epoxy) blended with Deproteinized Natural Rubber (DNR) in order to determine the mechanical properties of the composite and compare with Polyacetal based composites to know performance.

2. Materials used

The materials with their unique properties used to cast the composite specimens as shown in the Fig. 1 (a), 1 (b) and 1 (c) are listed below.

a. Araldite LY 556 (Epoxy Resin)supplied by **fiber region**, Chennai (Viscosity @ 25°C: 1700mPa/S and @ 40°C: 650mPa/S, Gel time @ 25°C: 120-180 mins and @ 40°C: 30 mins).

b. Aradur HY 951 (Catalyser) supplied by **fiber region**, Chennai (10-12 parts per unit).

c. Deproteinized Natural Rubber (Liquid) supplied by Shilpa Latex Product, Bangalore (DRC by weight: 60%, TS by weight: 61.4%, Colour: white).

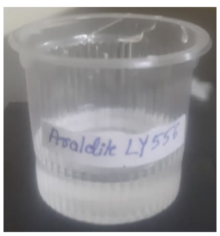


Fig. 1. (a) Araldite LY 556

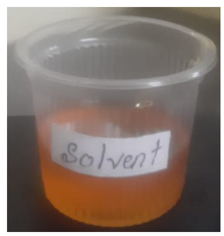


Fig. 1. (b): Solvent

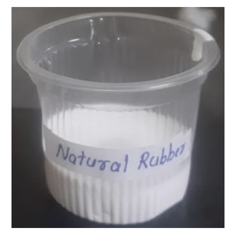


Fig. 1. (c): DNR

3. Characterization of cured epoxy filled with DNR

Since, the rule of mixing is by weight method, therefore, it is important to find out the Epoxy Equivalent Weight (E.E.W.) to determine the stoichiometric ratios for the manufacturing of the proportional composites as per weight percentage. It can be calculated by using the following equation;

$$\text{Epoxy Equivalent Weight (E.E.W.)} = \frac{(Total\ Weight\ of\ the\ mixture)}{\frac{(Weight\ \%\ of\ first\ material)}{(E.E.W.of\ first\ material)} + \frac{(Weight\ \%\ of\ second\ material)}{(E.E.W.of\ second\ material)} + \frac{(Weight\ \%\ of\ third\ material)}{(E.E.W.of\ third\ material)} + \frac{(Weight\ \%\ of\ fourth\ material)}{(E.E.W.of\ fourth\ material)}}$$

Table 1
E.E.W. for Materials Used

Materials Used	E.E.W. (g)
Araldite LY 556	235
Aradur HY 951	20.6
Solvent	190
DNR	400

Table 2
Composite weightage and Composite E.E.W

Specimen	Araldite LY 556		Solvent		DNR		Aradur HY 951		Total weight of mixture		E.E.W.
	(%)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(g)
C1	80	24	10	3	00	0	10	3	100	30	34.14
C2	75	22.5	10	3	05	1.5	10	3	100	30	34.49
C3	70	21	10	3	10	3.0	10	3	100	30	34.84
C4	65	19.5	10	3	15	4.5	10	3	100	30	35.20
C5	60	18	10	3	20	6.0	10	3	100	30	35.76

Note: *C = Composite

1. Huntsman Advanced Materials (parscomposite.com)
2. https://www.t-e-klebetechnik.de/en/adhesives/araldite.php
3. Selig, W S. Determination of equivalent weight of epoxides. United States.
4. http://www.epoxychemicals.com/files/Download/Calculating+Equivalent+Weight+of+Epoxy+Mixtures[1].pdf

From the above data, the stoichiometric ratio for mixing is 100:10 (resin : catalyst) parts by weight as per the data sheet provided by the manufacturer.

4. Composite mixture

With the materials listed in respective proportions in the Table2 and Table 3, specimens are casted independently, as per ASTM standards listed in Table 4. The method followed in casting is detailed in Fig. 3. There are two sets of specimens casted. The former, is strengthened by a DNR supported by Solvent and Aradur HY 951 catalyst to produce homogenous mixture for which a stirring action is carried out intermittently for duration of 10 to 15 minutes post mixing each material. With standardized cavities, casting is carried out as shown in the Fig. 2. The solidification and curing process is allowed at ambient temperature for 12 to 14 hours. The latter is a pure polyacetal material.

Table 3
Polyacetal Weightage

Sl. No.	Specimen	Polyacetal		Total Weight of Mixture	
		(%)	(g)	(%)	(g)
1.	D1	100	30	100	30

(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 2. (a) Casting Process, (b) Araldite-DNR casting, (c) Polyacetal casting, (d) Tensile test on Araldite-DNR specimens, (e) Impact test on Araldite-DNR specimens, (f) Tensile test and Impact test on Polyacetal specimens, (g) Vickers Hardness test on Polyacetal specimen, (h) Vickers Hardness test on Araldite-DNR specimen

Table 4
ASTM Standards for Specimen Preparation

Tests Conducted	Specimen Standard
Tensile Test (Polyacetal)	ASTM D638 type I
Tensile Test (Araldite-DNR)	ASTM D638 type I
Izod Impact Test (Polyacetal)	ASTM D 5628
Izod Impact Test (Araldite-DNR)	ASTM D 5628
Charpy Impact Test (Polyacetal)	ASTM D6110
Charpy Impact Test (Araldite-DNR)	ASTM D6110
Bending Test (Polyacetal)	ASTM D7264
Bending Test (Araldite-DNR)	ASTM D7264
Vicker's Hardness Test (Polyacetal)	ASTM E 384
Vicker's Hardness Test (Araldite-DNR)	ASTM E 384

5. Casting process

The specimens prepared as per Fig. 3 and Table 4 are fed to various experimental assessments. Tensile test on specimens (as shown in Fig. 2 (d & f)) is carried out on Instron testing machine, records noted are from the high calibrated modules. Impact Tests for Izod (U-notch) and Charpy (V-notch) (as shown in Fig. 2(e) and Fig. 2 (f)) and Bending Test are conducted on Instron Impact Testing Systems and Instron Bending Test Machine. The Hardness Test conducted on Nanatom Machine, a highly calibrated system for hardness testing of materials is conducted.

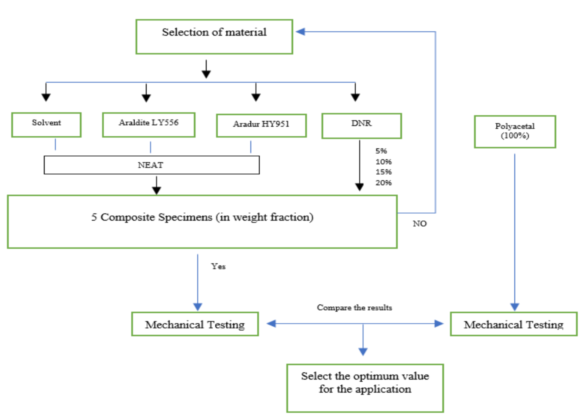
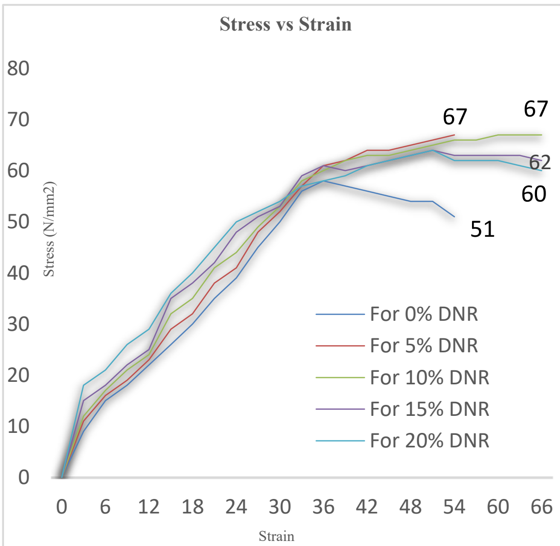


Fig. 3. Casting Process

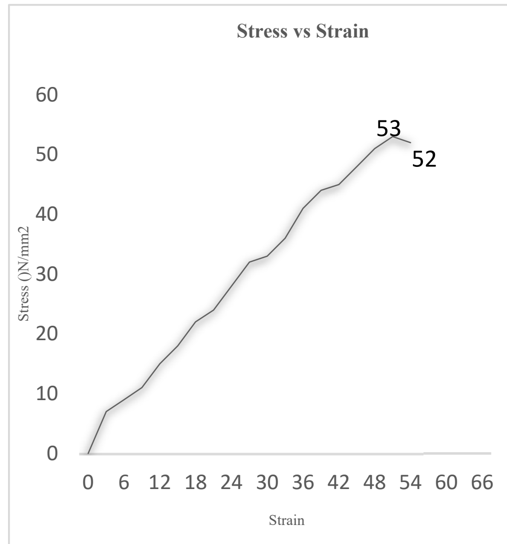
6. Results and discussion

6.1 Tensile test

From the tests conducted on ASTM standard specimens as shown in the Fig.2 (d& f) and Table 4 on Instron Tensile Testing Machine, the Polyacetal has better strength in comparison to neat Araldite casting. In addition to DNR, the tensile strength and strain rate gradually increases, possessing better strength in comparison to the former two as shown in the Graph 1 and Graph 2. At around 58 MPa, the composite changes from elastic zone to plastic zone and the strain at this point is 33. By increasing in the DNR the strain in the composites also increases.



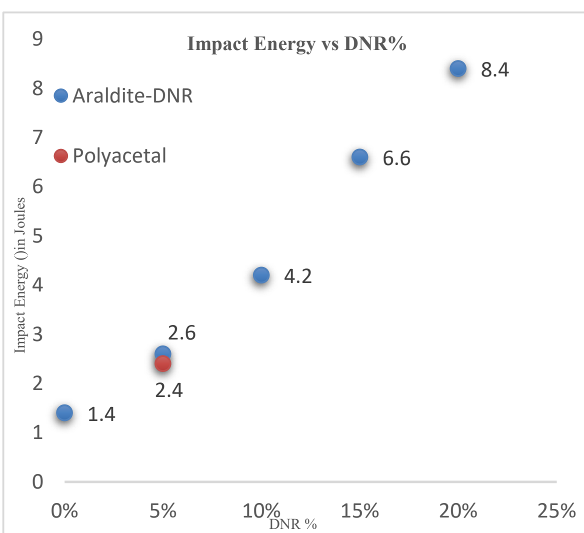
Graph 1. Tensile Strength (Araldite-DNR)



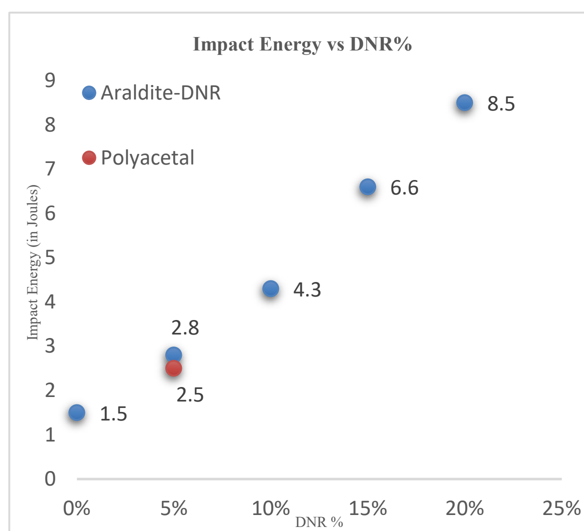
Graph 2. Tensile Strength (Polyacetal)

6.2 Impact test

From the tests conducted on ASTM standard specimens as shown in Fig. 2 (e & f) and Table 4 on Izod Impact and Charpy Impact Testing Machines, the neat Araldite in both cases exhibit a lower impact resistance in comparison to Polyacetal. In addition to DNR, the resistance property of the composite increases considerably. As results show, the behavior of the material changes in addition to DNR and as the proportion increases the impact resistance property also increases.



Graph 3. Izod Impact Test



Graph 4. Charpy Impact Test

6.3 Hardness test

From the tests conducted on ASTM standard specimens as shown in the Fig. 2 (g & h) and Table 4 on Nanatom Vicker's Hardness Testing Machine, the neat Araldite at 3500mNor 3.5N loads, displace and retract better than Polyacetal. However, in addition to DNR, the load bearing property increases considerably. The behavior of the material is changed by addition of DNR and improves the hardness value and impact resistance.

Table 5
Hardness Test for Polyacetal and Araldite-DNR Composites

Mixture	Pmax (mN)	hmax (nm)	Hv	Hit (GPa)	Er (GPa)	Eit (GPa)	Stiffness	Ap (nm^2)	Hv (nm)
PO	3503.728	30885.88	21.4600	0.2275	3.1050	2.8325	428.8950	15786268515	24923.15
Neat	3506.256	28830.58	24.2775	0.2648	3.8248	3.4937	503.4646	13650452687	23608.29
5% DNR	3502.330	35590.05	21.8500	0.2285	3.4075	3.1000	579.4825	27329644308	31049.34
10% DNR	3503.355	31593.79	18.5150	0.1950	3.5300	3.2200	524.2375	18038684038	26715.62
15% DNR	3503.250	35096.84	14.8200	0.1575	2.9550	2.6950	492.4875	22631968098	29903.31
20% DNR	3503.768	39713.66	10.8775	0.1175	2.6775	2.4425	517.8250	30417088279	34773.71

Note: Pmax = Maximum Pressure, hmax = maximum height, Hv = Vickers Hardness Value, Hit = Indentation Hardness, Er = Reduced modulus of the indentation contact, Eit = Modulus of Indentation, Ap = Area of indent Hc = Depth of the Contact of the indenter with the test piece at Pmax

Atomic Force Microscopic Images for Pre and Post Indentation

From the tests conducted on ASTM standard specimens as shown in Fig. 2 (g & h) and Table 4 on Nanatom Vicker's Hardness Testing Machine, The microscopic representation shows pre and post indentation on the specimen. The palmquist crack lengths in the post indentation stage, depicts the ability of the material to withstand the loads. The indent depth describes the molecular bonding between the DNR and Araldite as shown in the figure 4 (a to e). As the proportion of the DNR in the composite increases the indent depth reduces it due to the strong adhesive nature of DNR which incompasses the loads applied while indentation.

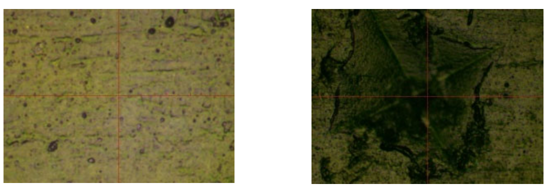


Fig. 4 (a) Neat Araldite structure

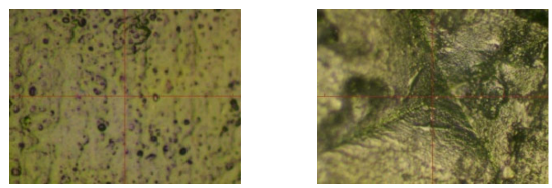


Fig. 4 (b) 5% Araldite-DNR structure

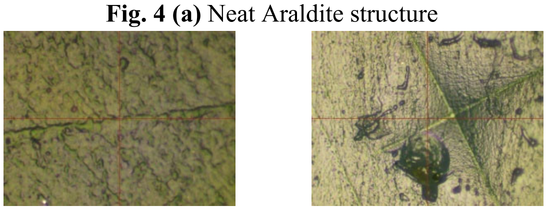


Fig. 4 (c) 10% Araldite-DNR structure

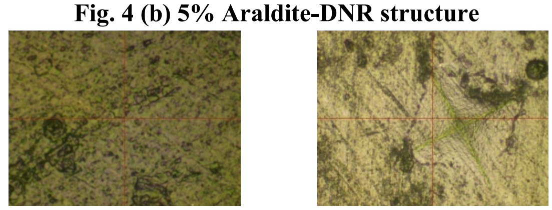


Fig. 4 (d) 15% Araldite-DNR structure

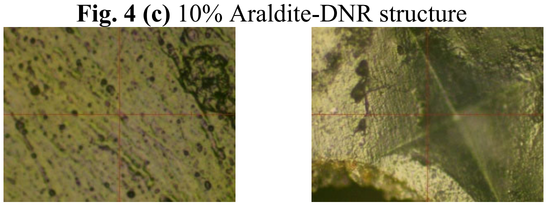


Fig. 4 (e) 20% Araldite-DNR structure

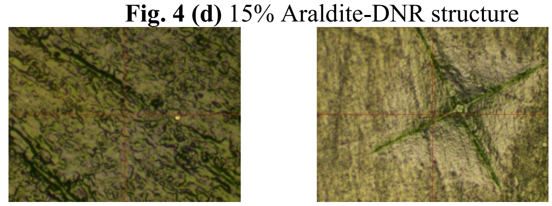
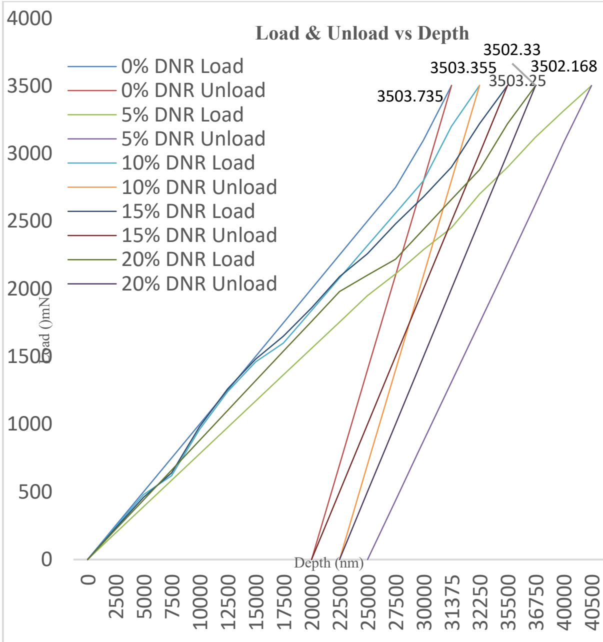


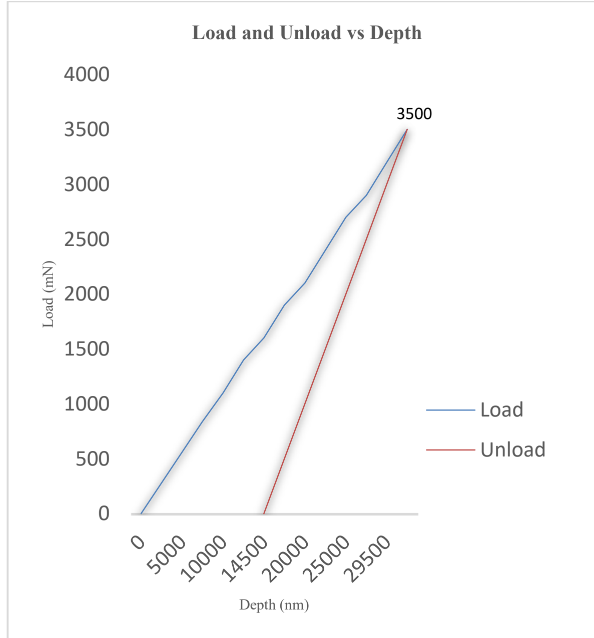
Fig. 4 (f) Polyacetal structure

The microscopic images as shown in Fig. 4 above depicts the pre and post indentation behavior of the composite specimen. In case of the Araldite-DNR composite the DNR proportion in the composite helps in strengthening the bond of the material and gives an edge over Polyacetal material.

From the graphical representation above it is evident that the loading and unloading condition of the composite at 3500 mN or 3.5N gives a strong momentum to the composite to portray good strength. The depths observed range from 20000 nm or 0.02mm to 27500 nm or 0.0275mm. These depths help in finding out the hardness value of the material as the hardness value is directly proportional to the depth of surface indentation and area of the indent. Similarly, in the case of Polyacetal the depth observed is 14500 nm or 0.0145mm.



Graph 5. Vicker's Hardness Test (Araldite-DNR)



Graph 6: Vicker's Hardness Test (Polyacetal)

The hardness value is calculated in the Rockwell hardness testing machine. The effect of the DNR weight % in the araldite LY556 is shown in the table below. It found that hardness of the Araldite LY556 is reduced by addition of the DNR in the Epoxy linearly it reduces with respect to the DNR as shown in the figure below.

Designation of composition	DNR (wt %)	Hardness
C0	0.0	46
C1	5%	45
C2	10%	42
C3	15%	38
C4	20%	36

Fig. 5. hardness value of the composite in Rockwell hardness testing

6.3 Bending test

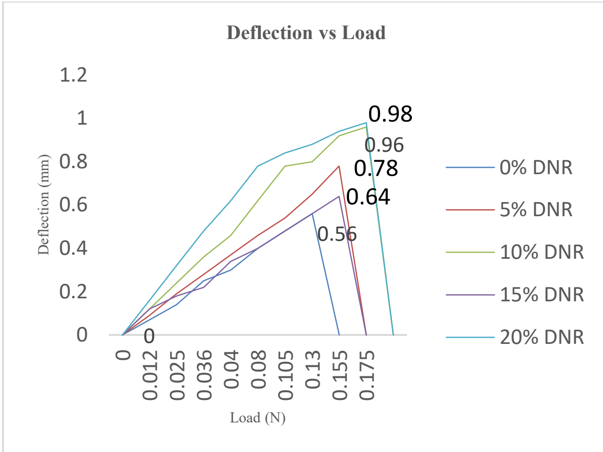
Fig. 6. Bending test specimen

From the tests conducted on ASTM standard specimens as detailed in Table 3 on Instron Bending Testing Machine, the neat Epoxy has a displacement of 0.56. As the DNR mixture is increased, the strength of the composite also increases considerably in comparison to the Polyacetal.

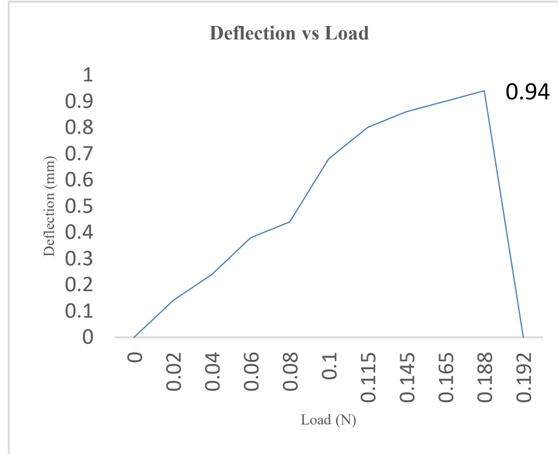
Table 6

Bending strength for Polyacetal and Araldite-DNR Composites

Composite Mixture	Size of the Specimen (l × b × h) in mm	Ultimate Load (in N)	Fracture Load (in N)	Max Deflection (in mm)
PO	120 × 10 × 3 mm	0.188	0.192	0.94
Neat	120 × 10 × 3 mm	0.140	0.150	0.56
5% DNR	120 × 10 × 3 mm	0.190	0.200	0.64
10% DNR	120 × 10 × 3 mm	0.188	0.192	0.78
15% DNR	120 × 10 × 3 mm	0.165	0.175	0.96
20% DNR	120 × 10 × 3 mm	0.175	0.210	0.98



Graph 7. Bending Test (Araldite-DNR)



Graph 8. Bending Test (Polyacetal)

It is evident that in the bending test as the DNR increases, the load carrying capacity of the specimen also increases. This is due to the bonding ability of the DNR along with Araldite. The DNR increases the elasticity of the overall composite which indirectly increases the overall load carrying capacity giving an edge for the composite developed over Polyacetal. As it can be witnessed from Graph 7 and Graph 8, the specimen casted with 20% DNR has maximum ability to deflect than the Polyacetal material, this shows that the DNR plays a pivotal role in the enhancement of bending strength.

7. Conclusion

With the better Tensile, Bending and Impact strength at 10% ratio and the ability to have greater toughening property with DNR pitches, the Araldite-DNR composite can be an alternative to the Polyacetal in the high strength and loading applications such as gears in Photocopying machines, handles, etc. The following are the observations.

From the bespeak, the tensile strength for the 5% and 10% DNR ratio in Araldite-DNR composite is 67N/mm^2. However, at a 10% ratio the Strain rate for the composite is considerably more, giving an edge for the composite to bear loads.

The increments in DNR percentage in the composite tends to increase the toughness which in turn increases the impact resistance. In neat Epoxy, the impact energy is the leanest and in addition to DNR the ability to resist impacts also gradually increases due to the increased toughening property. At 20% DNR, the impact energy witnessed is 8 Joules in comparison to the Polyacetal which has a capacity of 2.5 Joules (an increment by3.2 times).

At loads of 3500mN or 3.5N, the composite specimens fed under hardness tests exhibit some formidable results. The displacements for Araldite-DNR composites (depth in nm) observed ranges from 31375nm to 40500nm, with 20% DNR ratio exhibiting the highest. The Polyacetal has the lowest displacement in comparison to 20% DNR. However, during offloading the rebounding for Polyacetal is 14500 nm while for 20% DNR is 25000 nm. Due to this the stiffness property of 20% is also more compared to Polyacetal. However, the hardness value (hv) in both cases is 21.46 and 21.85 respectively. From the molecular structures as seen in the Fig. 4 ((a), (b), (c), (d), (e) and (f)) the homogenous mixture of the material is exhibited along with the indentation depths during testing for hardness.

In comparison to the bending for Polyacetal and DNR composites, the later with 10% DNR mixture portrays a deflection of 0.98mm in contrast with 0.94mm for the Polyacetal. However, the 20% ratio specimen shows slightly higher deflection ability but the material develops porosity in it.

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