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Determination of Mechanical Properties of Natural Cactus Adhesive

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Abstract

The purpose of this paper is to determine mechanical properties on effect of curing time of natural cactus adhesive and compare with other adhesives. Tensile test on bulk cactus specimen stayed at room temperature and humidity for 5 days, 7 days and 11 days respectively were performed to determine the effect of curing time using Universal Testing Machine (UTM). The range of mechanical property results for the different curing time was found young's modulus (631.16-1507 MPa), tensile stress (76.73-118.68MPa) and strain (6.61-12.52%). When compare to other adhesives, cactus adhesive was found less stiff than AV 119 and Sika power 4720 adhesive but better tensile strength and strain. After 11 days of curing time, Cactus adhesive is found less stiff, but after 5 and 7 days curing time it is stiffer than XNR 6852 adhesive. XNR 6852 adhesive is found more strain than cactus adhesive.

Key words: adhesives, curing time, natural cactus adhesive, AV119, XNR 6852, bulk specimen, UTM, stiff

I. Introduction

A cactus is a member of the plant family Cactaceae, a family comprising ca 127 genera with some 1750 known species of the order Caryophyllales. Cactus spines are produced from specialized structures called areoles, a kind of highly reduced branch. It is a plant with very thick and fleshy stems. It is often covered with prickles and it grows in desert and semi desert area of the world which is high tolerant to drought (Barbera, 1995). Cactus crop contains water (92%), carbohydrates (4-6%), protein (12%), minerals (1%), and moderate amount of vitamins mainly A and C [12]. Cactus has different benefit such as source of food, medicine, chemical and income. Therefore, the general objective of this research was carried out to assess the economic benefit of cactus as potential source of food for both human and animal in Mekelle District, Northern Tigray region of Ethiopia. Even though the area is characterized by a potential on cactus crop but the farmers used cactus crop only as diet for human being and as forage for animals particularly for cattle. Mechanical properties effect on Curing time of natural cactus adhesive using dogbone tensile specimens analysis were carried out in this study. Ethiopia is one of the well-endowed countries in terms of natural resources including fauna and flora [14]. However, the country faces different problems like soil erosion [14].The cause for this is manly associated with land cover change [13]. Even though different parts of Cactus is used for preparing juice and medicine, but the households did not use cactus as a source of juice and medicine. Only 2.96% of the households replied that cactus crop used as preparing medicine and 22% of households replied that cactus crop used for preparing juice or Tej (local drink). An adhesive is a polymeric material that binds two surfaces together and resists separation. Based on the source from which they are made adhesives classified into natural and synthetic adhesives. Synthetic adhesives classified into elastomers, thermoplastic and thermosetting. Elastomers are rubber like elastic material with low strength and more flexibility. Thermoplastic adhesives are hard at room temperature but on heating become soft and more or less fluid but better in strength than elastomers. Thermosetting adhesives can be molded at room temperature or above but when heating more strongly become hard [10, 11]. Until recent time only conventional method of assembly like welding, riveting, screwing and bolting was used. But conventional method of assembly had problems like increase weight of assembly, increase time of assembly, create local stress to failure and increase cost of assembly [2, 7 and 9]. After that many researchers were engaged to determine a mechanical property of adhesives performed. And they found adhesive solve the above problems of conventional assembling methods. Adhesives nowadays used in assembling wood furniture, automotive, shoe, aero- plane etc. [2, 6, 7, 9 and 11]. In villages of Ethiopia (Tigray region) cactus natural adhesive had been in use in fastening wood and paper for years. But the peoples in the city who produce wood furniture do not use cactus natural adhesive rather other imported from abroad. This was because no scientifically studied design data available that could be used to predict failure strength during design.The purpose of this paper was to determine mechanical properties of cactus natural adhesive, effect of curing time and compare with other adhesives. This was performed based on bulk tensile test [5] according to French standard NF T76-142[1]. The "dogbone" standard specimen was prepared followed by BS 2782 [6].The aim of this work is the investigation of the effect of the mechanical performance of bulk natural cactus adhesive.

II. Materials and methods

The study was conducted in Mekelle District, Northern Tigray Zone of Tigray State in 2015. The District was selected due to the fact that there was more cactus is growing in the Mekelle University area. For this study descriptive type of research was employed to describe the mechanical characteristics of variables in the study area. Material characteristics required for the determination of mechanical properties such as yield stress, ultimate stress, young's modulus, strain at ultimate and stress-strain diagram of a natural cactus adhesive specimens were fabricated and preparation followed by BS 2782 dogbone tensile test standards. The two tensile test approaches can be used to determine the mechanical properties of adhesive are bulk specimen and joint [5]. In this research bulk specimen approach was used to determine the mechanical properties of natural cactus adhesive because it was easy to perform and follow standard for plastics [6]. To prepare bulk cactus sheet, metal mold was required. And the mold was prepared according to French standard NF T 76-142[1] dimension. Parts of the metallic mold were mold base, mold lid, metallic box front and metallic box side. The metallic mold was drawn using a CAD modeling software CATIA as shown in Figure 2.1 below based on the dimension on the French standard NF T 76-142. After modeling, manufacturing drawing was prepared with the same software and manufactured using milling and drilling machine on the EIT-M Mechanical and Industrial School.

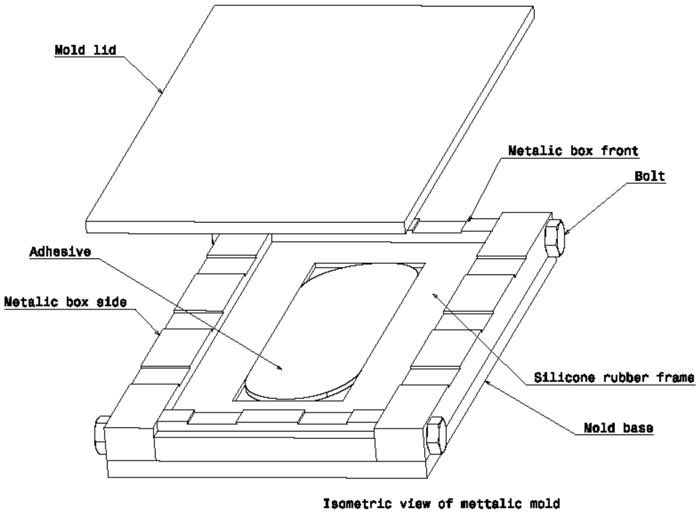


Figure.2.1. CAD model of metallic mold according French standard NFT 76-142

After the mold was manufactured the actual photo presented as shown in Figure 2.5 (d) below. The silicone rubber in the model shown in Figure 2.1 above was used to seal adhesive. Therefore in this research the silicone rubber was prepared from silicone liquid using the mold in Figure 2.5(d). The silicone liquid with the container as shown in Figure 2.2 was bought from market. After weighing the required quantity of silicone it was put inside the metallic mold to press with 35KN using aggregate crushing machine to get the required size [5]. The immediate shape was rectangular shown in Figure 2.3 given below. The silicone also used as releasing agent to prevent the adhesive from wetting the silicone surface [3, 4].

Figure.2.2. White silicone fluid **Figure.2.3. Silicone rubber frame manufactured based on French standard**

Before cactus was poured into the mold, the mold was painted with releasing agent (silicone) not to fasten with cactus. It does not fasten with most adhesive materials [1]. The detail drawing of mold according to the French standard for manufacturing cactus adhesive specimen drawn using Catia software. The cactus fluid was brought from a place near the EIT-M University. The cactus tree while bleeding and the collected white fluid from the tree were as shown in Figure 2.5(a) and Figure 2.5(b) respectively. The fluid from cactus tree was changed to solid at environmental temperature and humidity within one day (24hours). After the fluid changed to solid based on the required amount it will be weighed as shown in Figure 2.5(c). After that it is poured into the mold as shown in Figure 2.5(d) and Figure 2.5(e) below to be pressed. After the weighed cactus adhesive poured into mold it was pressed with 2MPa pressure using aggregate crushing machine with 335KN capacity to get the required thickness cactus sheet according to bulk adhesive specimen preparation standard [1] as shown in Figure 2.5(f) below. After pressing of the cactus adhesive with the required load the cactus sheet looked like as shown in Figure 2.5 (g) inside the mold and Figure 2.5 (h) outside the mold respectively. The pressing time was within few seconds the curing of cactus takes place outside of the mold. Preparation of bulk cactus sheet using mold is shown in Figure 2.8 below. Tensile loading is a favorable type of loading, because it produces a relatively uniform stress distribution. A silicone rubber frame seals the cactus fluid from flowing out of the mold and determines thickness of the specimen during pressure application. The external dimension and thickness of cactus solid sheet determined from the internal dimension and thickness of silicone rubber frame respectively. The detail standard BS 2782 dogbone tensile test specimen dimension [6] used in this research as shown in Figure 2.4 below.

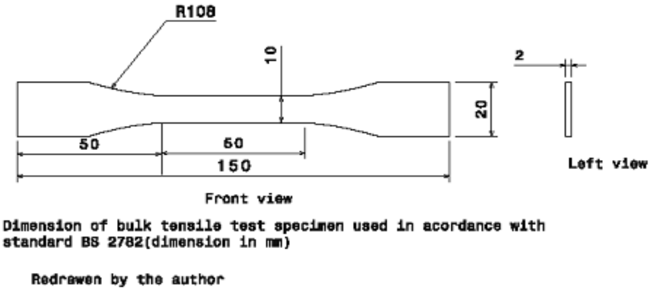
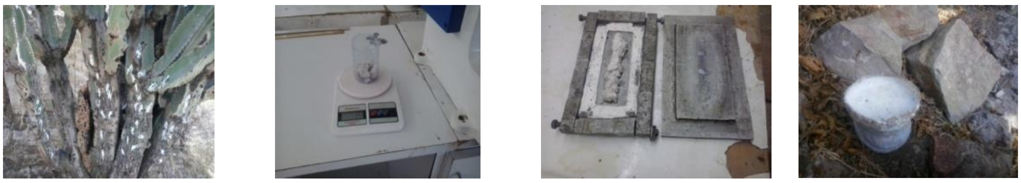


Figure.2.4. Dimension of the bulk tensile test specimen

The 2 MPa pressure applied on the cactus creates a good surface finish. The dimensions of cactus solid sheet after cure were 150mm*45mm with a thickness of 2 mm which corresponds to the internal dimension of the silicon rubber frame [1, 5]. The dimension of the dogbone tensile test specimen based on BS 2782 standard dimension is as shown in Figure 2.4 above.Based on the dimension on standard BS 2782 the cactus sheet on Figure 2.5(h) was changed to the dog bone tensile test specimen as shown in Figure 2.5 (i) using razor blade for cutting on hand, compass and ruler for measurement. The machine used in this research was a universal testing machine (testometric) M500-50KN capacity machine as shown in Figure 2.6 (j). Load was applied to the specimen through the crosshead, connected to a load cell. The pair of grips that match the specimen under test was chosen Figure 2.6 (k), and the 500kgf load cell installed. One grip was mounted to the base of the testing machine and one to the crosshead using pins and bolts provided. The flat side of both grips was parallel to the crosshead. The grips were equipped with pin facilitating a correct positioning of the specimen. The specimen was placed inside the grips where the knurl (rough surface) on the grip tightens the specimen on both sides. The Testing Machine controller was set to raise the crosshead at a speed of 1 mm/min [6], Gauge length 50mm. The thickness and the width of the specimen were also introduced, and the needed output parameters set on. The specimen was not pre-loaded. As the test begins (by pressing the play button), the drawing of the stress/strain diagram, all the required data such as maximum stress, yield stress etc. was continuously displayed. The result of reading data based on the input was displayed on the screen of computer of the machine. After that the data was taken by capturing through zoom camera on the smart mobile phone. The data are likely ultimate stress, yield stress and stress-strain diagram.



(a) (b) (c) (d)

(e) (f) (g) (h) (i)

Figure.2.5. Cactus adhesive specimen manufacturing process a) Cactus tree bleeding b) cactus fluid from cactus tree c) Weighing dried cactus (33g) d) actual photo of the manufactured mold e) Solid cactus product inside mold f) cactus pressed with 35KN force using aggregate crushing machine (335KN capacity) g) cactus sheet inside mold h) cactus sheet after removed from mold i) dogbone specimen prepared based on BS 2782

(j) (k)

Figure.2.6. M500-50KN test metric machine for tensile test (j) whole machine k) specifically the jaws

The cactus fluid after it brought to the EIT-M lab takes 24 hours to solidify but it does not mean it is completely dried. After solidification the cactus sheet was prepared and the specimen was preceded. After preparation of the cactus sheet it was kept dry at the room temperature maintained humidity in material testing lab of school of Mechanical and Industrial Engineering of EIT-M. But to determine the curing time (optimum mechanical properties of cactus) testing of the specimen time range was necessary. To eye visualization and touch the specimen, it was dried until 5 days. Silicone one of the fastening materials got the optimum mechanical property after 7 days according to the cover on silicone container prescribes. Based on the above two reasons to get the optimum mechanical properties of cactus three tests at different period of time were performed. The tests were performed alternatively five, seven, and eleven days after manufacturing.

III. Experimental results

The tensile test specimens were subjected to uniaxial load until they failed in the universal testing machine (testometric) as mentioned in the research methodology above. The load was applied at a fixed displacement rate of 1 mm/min until failure. The tests were performed at room temperature and humidity in material testing lab of school of Mechanical and Industrial Engineering, EIT-M, Mekelle, Ethiopia. The tests were performed at alternative days because the curing time of natural cactus adhesive were not known. The stress-strain diagram and mechanical property of failure strength test results of four number of cactus specimen stayed at EIT-M room temperature and humidity for five, seven and eleven days after manufacturing [6] are shown in Table 3.1 given below.

Table 3.1: Experimental results of uniaxial tensile tests

Test No.	Tensile Stress (MPa)	Young’s modulus (MPa)	Strain (%)
1	106.15	1191	10.692
2	137	1067.9	13.268
3	128.8	1190.7	15.168
4	102.75	1285.2	9.46
Mean(calculated)	118.68	1183.7	12.15
SD(calculated)	16.82	89.09	2.57

Based on the statistical method, outlier data points was rejected according to the document measurement uncertainty (ASTM, 1998), later on modified by Thompson technique (T) [8]. Errors were considered like human, machine etc. Based on Thompson technique, data may be rejected if (largest data minus mean) or (smallest data minus mean) were greater than SD*T where the Thompson had different value for different sample size from table [8]. For remaining sample sizes the procedure repeated until no data obtained to be rejected. The final test result obtained as shown in Table 3.2 given below.

Table 3.2: Average failure strength test result of cactus stayed at room temperature and humidity for 5 days

Average tensile stress(MPa)	Average young’s modulus (MPa)	Average strain (%)
118.68±16.82	1183±89.09	12.15±2.56

Table 3.3: Failure strength test results of cactus stayed for 7days at room temperature and humidity

Test No.	Tensile Stress (MPa)	Young’s modulus (MPa)	Strain (%)
1	96.8	1478.9	10.09
2	97.9	1411.3	7
3	95.55	1632.5	5.95
4	78.35	955.73	6.88
Mean(calculated)	92.15	1369.61	7.48
SD(calculated)	9.25	291.03	1.8

The procedure to reject datas because of human, machine errors were lying the same in the above section. The final average mechanical proporties are shown in Table 3.4 below.

Table 3.4: Average failure strength test result of cactus stayed for 7 days at room temperature and humidity

Average tensile stress(MPa)	Average young’s modulus (MPa)	Average strain (%)
96.75±1.18	1507.57±113.35	6.61±0.57

Table 3.5: Failure strength test results of cactus stayed for 11 days at room temperature and humidity

Test No.	Tensile stress (MPa)	Young’s modulus (MPa)	Strain (%)
1	96.150	1511.6	11.782
2	67.850	658.89	12.8
3	53.800	485.89	9.55
4	89.100	748.69	13
Mean(calculated)	76.73	851.27	11.78
SD(calculated)	19.45	453.53	1.58

The procedure to reject outlier data is the same with the above two sections and the final average values are shown in Table 3.6 given below.

Table 3.6: Average failure strength test result of cactus stayed for 11 days at room temperature and humidity

Average tensile stress (MPa)	Average young’s modulus (MPa)	Average strain (%)
76.73±19.45	631.157±133.577	12.527±0.65

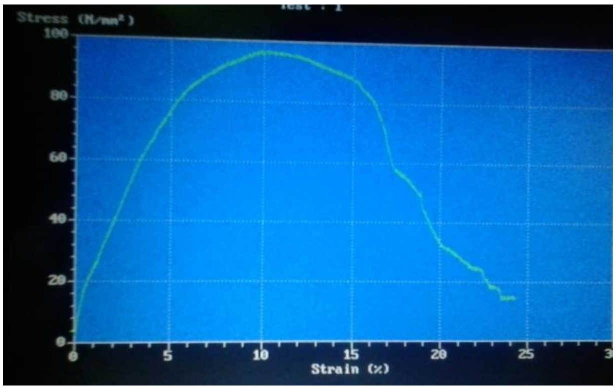


Figure 3.1. Strain diagram result of cactus.

Figure 3.2.Tensile test specimen of cactus

IV. Discussion

Table 4.1: Comparison of young's modulus, tensile strength and strain of cactus at different curing time

Number of days	Tensile strength(N/mm^2)	Young's modulus (N/mm^2)	Strain (%)
5	118.68±16.82	1183±89.09	12.15±2.56
7	96.75±1.18	1507.57±113.35	6.61±0.57
11	76.73±19.45	631.157±133.577	12.527±0.65

The mechanical property of cactus varies when tested at variation of days, as a result of curing time difference. As shown from Table 4.1 and Figure 4.1, the cactus become stiffer when stayed for 7 days and less stiff at 11 days, more strength at 5 days and less strength at 11 days, almost similar strain at 5 and 11 days, less strain at 7 days. These differences in stiffness were expected because the cactus adhesive inside a cactus tree has different environment than outside. The tensile test specimens were prepared after the cactus fluid changed to solid at room temperature and humidity within 24 hours. Cactus became solid but not completely cure was also expected to be affected within the environment with time. The cactus solid was very rigid. The solid cactus adhesive was below the glass transition temperature (temperature at which adhesive change from glass like to rubber like structure) when the specimens were prepared and tested. But since adhesive affect by temperature and humidity cactus also the same.

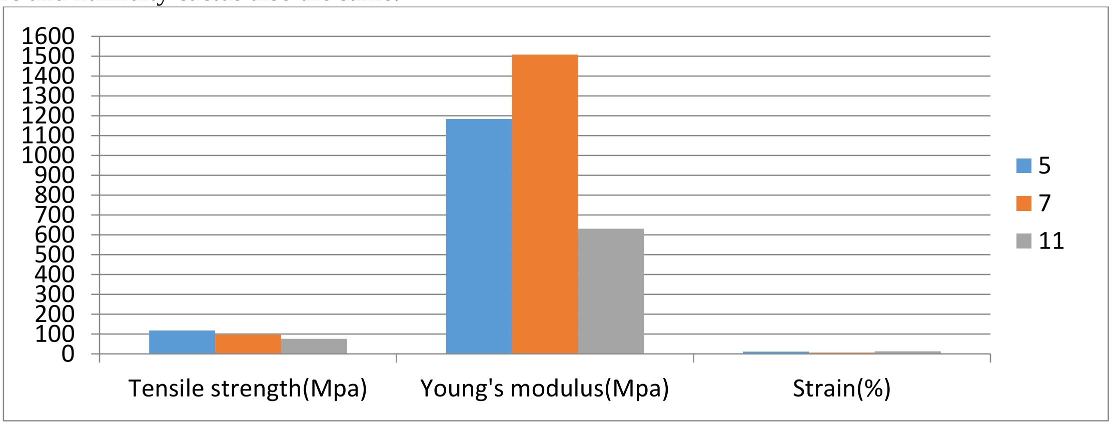


Figure 4.1. Comparison of tensile strength, young's modulus and strain at 5, 7 and 11 days for cactus adhesive

The adhesives which were used for comparison with natural cactus adhesive that was studied in this thesis were: - The adhesive XNR 6852 (thermoplastic, linear structure), Sika power 4720 (thermosetting, cross-linking structure) and toughened epoxy adhesive AV119 (thermosetting, cross-linking structure) [6].This work deals with the determination of cure-dependent mechanical properties, especially the young modulus, strain and the tensile strength. Bulk tensile specimen of the three adhesives and natural cactus adhesive that was studied in this thesis was prepared based on the French standard NF T 76-142 mold (Figure 2.1) and the dimension of the dogbone specimen was according to the standard BS 2782 (Figure 2.4). The cactus adhesive is one-part system , cure at room temperature and curing time was checked at 5,7 and 11 days where as adhesive XNR 6852 (one-part system), Sika power 4720 (two-part system) and epoxy adhesive AV119 cure at 150°C, for 3hours and room temperature for 24 hours respectively [6] for the last two adhesives. For the three adhesives bulk tensile specimen were produced by curing the adhesive between steel plates of mold (Figure 2.1) [6] and the cactus adhesive prepared by the same mold but left in the room temperature for curing for 5,7 and 11 days. The test was performed at room temperature and constant displacement rate of 1mm/min with 4 numbers of specimens for all the adhesives. The mechanical analysis is shown in Table 4.2 given below.

Table 4.2: Comparison of natural adhesive cactus with XNR 6852, Sika power and adhesives

Adhesives	Tensile strength(MPa)	Young's modulus(MPa)	Strain (%)
XNR6852	59.9	1176.3	100.7
Sika power 4720	25	2030.9	4.9

AV119	60	2400	3
Cactus(5 days)	118.68	1183	12.15
Cactus(7 days)	96.75	1507.57	6.61
Cactus(11days)	76.73	631.157	12.527

The results on the mechanical behaviours of cactus adhesives are shown in the Figure 4.2. As shown in Figure 4.2 below and Table 4.2 above all test results of cactus adhesive at 5, 7 and 11 days were less stiff than the toughened epoxy AV119 and epoxy Sika power 4720 but cactus had larger tensile strength and strain. All cactus adhesive test result also had smaller strain than adhesive XNR 6852 but larger value in tensile strength. The cactus adhesive tested after 11 days were less stiff, cactus tested after 5 days almost the same and cactus tested after 7 days stiffer than the adhesive XNR 6852. Generally the cactus adhesive tested in three of the different days had greater value in tensile strength but had less stiff and less strain, compared to other three adhesives. The important mechanical properties: tensile strength and young modulus seem to reach their maximum values after 5 curing days and failure strain, more or less, remain near the 12 percent. The young modulus, however, increases with clay 7 day of curing initially and decreases thereafter 11 days of curing time.

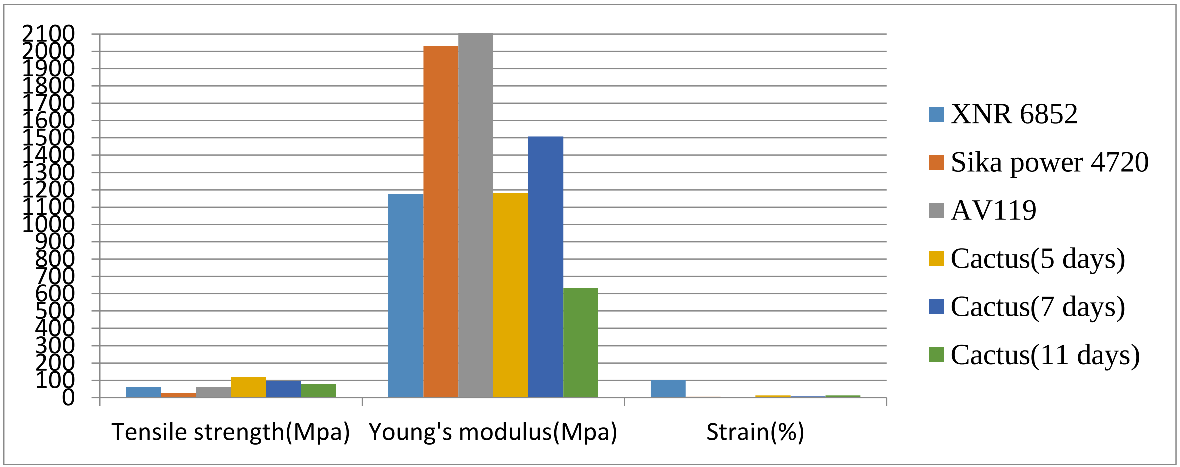
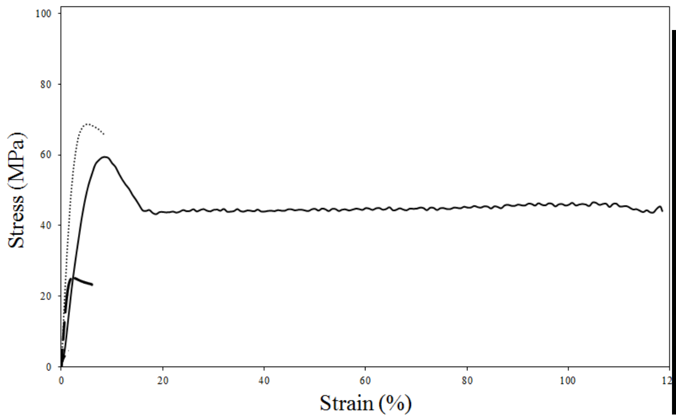


Figure. 4.2. Comparison of tensile strength, young's modulus and strain at 5, 7 and 11 days



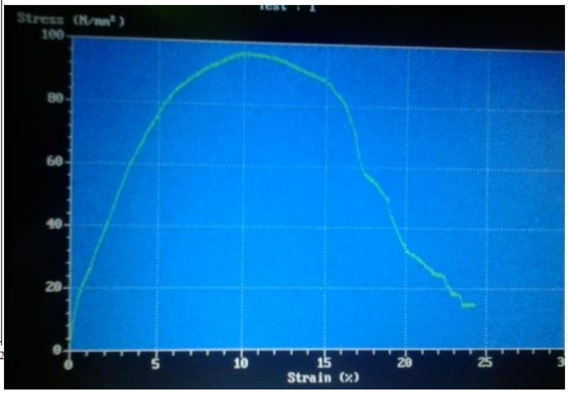


Figure. 4.3. Stress-strain diagram of XNR, Sika power and adhesives [6] Figure. 4.4. Stress-Strain diagram of cactus

The elastic behavior as shown in Figure 4.3 and Figure 4.4 for thermoplastic adhesive XNR 6852 and natural adhesive cactus respectively were result of two mechanisms. One when an applied stress causes the covalent bond within the chains to stretch and distort, allowing chain to elongate elastically. When the stress is removed recovery from this distortion is almost instantaneous. In addition entire segments of the polymer chains may be distorted; when the stress is removed, the segments move back to their original position over a period of time. This time dependent, or viscoelastic behavior contribute to the nonlinear elastic behavior on both diagrams [11]. That means the yield strength includes the non-linear elastic and linear elastic diagram part. The yield strength and tensile strength was the same for these polymers. The XNR 6852 on the diagram after yield strength reached had large plastic deformation which leads to large strain because the chains can rotate and slide where as the cactus breaks after yield strength with little plastic deformation. The difference may be incurring time and temperature because XNR 6852, cure at 150°C, for 3 hour [6] where as cactus cure at room temperature and a week. Both adhesives become flexible as heated. Whereas the thermosetting adhesives AV119 and Sika power, both act as brittle manner with no elastic behavior because the chains cannot rotate and slide. But as the Figure 4.3 shows both are stiffer than the XNR 6852 and cactus adhesives. Thermosetting adhesive when heated cannot be flexible rather more hard [11].

V. Conclusion

In this paper, an approach for the relation of the cactus with thermoplastic and thermosetting adhesive degree of stiffness and the component of the young modulus is presented. The mechanical response of the resulting adhesive materials in dry conditioned states was investigated. A characterization of mechanical properties of natural adhesive cactus done with 5, 7 and 11 days of curing time and the values were found. The following conclusions have been drawn from the findings of our tests: Maximum (118.68MPa) and minimum (76.73MPa) tensile strength was found at 5 days and 11 days of curing time respectively. Maximum (1507MPa) and minimum (631.157MPa) young's modulus was found at 7 and 11 days of curing time respectively. Maximum (12.52%) and minimum (6.61%) strain was found at 11 and 7 days curing time respectively. Comparison of mechanical properties of natural cactus adhesive with thermoplastic adhesive XNR 6852, thermosetting adhesives toughened epoxy AV119 and Sika power 4720 was found as Cactus adhesive (5, 7 and11 days) was less stiff but larger tensile strength and strain than AV119 and Sika power 4720 adhesives. Cactus adhesive (5, 7 and 11days) has smaller strain than XNR 6852.Cactus (5 days) as stiff as XNR 6852, but cactus (7 days) stiffer and cactus (11 days) is less stiff than XNR 6852 respectively.

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