EFFECT OF REINFORCEMENTS COMBINATION ON THE MECHANICAL STRENGTH OF GLASS REINFORCED PLASTIC (GRP) HANDLA Y -UP LAMINATES UNDER INCREASED TEMPERATURE CONDITIONS

S. O. Edelugo
Department of Mechanical Engineering,
University of Nigeria, Nsukka, Nigeria

ABSTRACT

A number of hand lay-up GRP laminates of E-glass are produced in various reinforcements combinations. Careful record of their strength tested under room temperature is tabulated against each corresponding laminate. A close study of these results show that their laminate strength varied considerably from initial values, Strength of some combinations increased with increasing temperatures whereas those of some others dropped under the same increased temperature conditions. Investigations into finding suitable explanations for these strange behaviours by the afore-stated laminates remain in progress.

INTRODUCTION

The increasing use of GRP composites under elevated temperature conditions (wet and dry situations inclusive) has necessitated the improvement of the strength of such composites, which are made to serve within elevated temperature conditions with the primary aim of achieving a higher margin of safety and durability in operation[1,2]. Driers, boilers, pressure pipes, pressure vessels and speedboats are a few of such items that are required to operate within elevated temperature conditions. And, for obvious reasons, these equipment, at present are preferred in GRP rather than steel, aluminum, or any other materials employed previously in their manufacture [3]. One of the reasons being resistance to rusting when compared with mild steel; then cost, weight, flexibility of shape, heat conservation and indentation strength when compared with other metals such as aluminum, copper, lead, etc.

As early as the estimates of Voigt and Reuss, the strength of composites have always been shown to be directly proportional to their fibre volume fraction [4]. The only other factor considered to be of reasonable influence with regards to the strength of composites being their fibre - direction or orientation [5]. However, further works do reveal that the directional chance agreement of fibres sometimes exact an influence on the composite strength over and above the traditional fibre volume fraction dependence of composite strength [6]. The decision to undertake strength tests in tension, bending and indentation (hardness test) here goes a step further to rule out any influence in strength that may be credited to the orientation of fibres in any given direction.

The objective of this work is to find out what is the resultant effect strengthwise of combining fibre reinforcements during handlay-up laminations in varying proportions and within arrangement at random - particularly, when these laminates are employed in areas where elevated temperature conditions are operational.

EXPERIMENTAL PROCEDURES Materials

Six laminate specimens B, C, D, E, F and G having various reinforcements combination all of the E-glass family (selected at random) are employed for this purpose and produced in hand lay-up under similar laboratory conditions. The length, width and thickness of each specimen being made to conform to same size for all test samples (see tables5, 6,7,8,9. and 10). The tests are carried out under three subheadings: Tensile, Hardness and Bending and the test conditions also are three: first, tests on the untreated specimen for each subheading for each specimen sample: second; tests on specimen samples heated at 60^0C (dry) for twenty four hours for each subheading for each specimen sample and third: tests on specimen sample heated at $80°$C (inside water) for twenty - four hours for each subheading for each specimen sample. Note that the temperature ranges employed here fall within the values to which such items as: driers, pressure pipes, speed boat, etcetera all of which are made from fibre reinforced

laminates, operate.

Table 1 presents the various compositions of the laminates used in the experiment.

Table 1: **Laminate compositions**

Specimen involved	Ply composition
Specimen B	5 plies of woven roving
Specimen C	2 plies of (42.7g) hardmat 1ply of woven roving 2 plies of (42.7g) hardmat
Specimen D	1 ply of softmat 2 plies of (42.7g) hardmat 1 ply of woven roving 2 plies of (42.7g) hardmat 1 ply of softmat
Specimen E	8 plies of (42.7g) hardmat
Specimen F	2 plies of softmat 4 plies of (42. 7g) hardmat 2.plies of softmat
Specimen G	12 plies of softmat

Test method

The tests are carried out in the laboratory using a multipurpose bending, hardness and tensile test machine. In tensile test, the specimens are gripped at both ends by the machine and continuous loading is achieved by turning the wheels of the machine until ultimate failure of break-up of the specimen is achieved. On the graphical paper inserted in the machine's wheel drum, a graphical plot of the behavour or movement of the machine is obtained as the specimen is loaded up to failure or break up point. Similarly, for bending test, a horizontal displacement at mid-point of the specimen (gripped at both ends by the machine) is achieved by hand rotation of the wheels as described above. By ratio, the reading of the horizontal displacement is also transferred to the graphical paper by the intermittent push-plotter on the paper-carrying drum. At break-up, the maximum or ultimate bend strength is reached and the silver liquid indicator on the drum reading rushes back to its reservoir. The hardness test

Table 2: test Results: tensile test

| specimen | Fibre reinforcement composition | Tensile Test | | | Remark | |
| | | (a) | (b) | (c) | | |
		Strength of laminate untreated (Mpa)	Strength of laminate heated to 60^0C (dry) for 24 hours (Mpa)	Strength of laminate heated to 80^0C inside water for 24 hours (Mpa)	Behavior of laminate with increasing temperature	v_t
B	5 plies of woven roving	133.1	-	120.0	Strength decreases	0.71
C	2. plies of (42.7g) hardmat 1. ply of woven roving 2. plies of (softmat)	63.9	-	78.9	Strength increases	0.51
D	1 ply of softmat 2 plies of (42.7g) hardmat 1 ply of woven roving 2 plies of (42.7g) hardmat 1 ply of softmat	55.0	-	77.9	Strength increases	0.43
E	8 plies of (42.7g) hardmat	68.0	-	45.7	Strength decrease	0.45
F	2 plies of softmat 4 plies of (42.7g) hardmat 2.plies of hardmat	37.5	-	43.8	Strength increases	0.25
G	12 plies of softmat	76.5	-	44.6	Strength decreases	0.33

is also achieved in the same way. The only difference being that Brinnel balls arc used to achieve indentations on the specimen thickness. The indentation reaches a maximum at crack point of the specimen which is recorded by the push-plotter silver liquid indicator. This is the ultimate strength. The Brinnel hardness, Hb is calculated using the Brinnel equation:

$$H_b = \frac{P}{\frac{\pi D}{2}[D - \sqrt{(D^2 - d^2)}]}$$

Where:

D= Diameter of Brinnel ball used in mm
d = Diameter of Indentation produced in mm
P = Load value at failure or crack point in kilogramforce

RESULTS AND DISCUSSION

The results of the study arc presented in tables 2-4. All values below correspond to ultimate strength or strength of specimen at "break-up" point or at point at which crack initiates at the indentation hole. For a closer study here please see: (i) Tables 5 and 6; and figures 1,7,13 - showing laboratory test results and plots of specimen 'B' from where the results of tables (2-4) were taken. (ii) Tables 7 and 8; and figures 8 and 14 - showing laboratory test results and plots of specimen 'C' from where also the results in tables (2-4) were taken. (iii) Tables 9 and 10; and figures 3, 9 and 14 - showing laboratory test results and plots of specimen 'D' whose summary appear in tables (2-4). (iv) Figures 4, 10 and 16 - showing plots of the test results of specimen F whose summary is contained in tables (2-4) and, finally (vi) figures 6, 12 and 18 - showing detailed plots of the test results of specimen G which is found contained in brief in tables (2-4) as well.

Table 3: test result: hardness test.

		Hardness Test			Remark	
		(a)	(b)	(c)		
specimen	Fibre reinforcement composition	Strength of laminate untreated (Mpa)	Strength of laminate heated to 60^0C (dry) for 24 hours (Mpa)	Strength f laminate heated to 80^0C inside water for 24 hours (Mpa)	Behavior of laminate with increasing temperature	v_t
B	5 plies of woven roving	1000.5	926.7	875.8	Strength decreases	0.71
C	2. plies of (42.7g) harmat ply of woven roving plies of (softmat)	407.4	513	548.9	Strength increases	0.51
D	1 ply of softmat 2 plies of (42.7g) hardmat 1 ply of woven roving 2 plies of (42.7g) hardmat 1 ply of softmat	651.8	560.4	667.0	Strength decreases	0.43
E	8 plies of (42.7g) hardmat	595.7	529.5	484.8	Strength decrease	0.45
F	2 plies of softmat 4 plies of (42. 7g) hardmat 2.plies of softmat	590.7	644.1	642.6	Strength increases	0.25
G	12 plies of softmat	751.0	869.7	682.3	Strength increases	0.33

Table 4: Test Results: Bending Test

		Bending Test			Remark	
		(a)	(b)	(c)		
specimen	Fibre reinforcement composition	Strength of laminate untreated (Mpa)	Strength of laminate heated to 60^0C(dry) for24 hours (Mpa)	Strength of laminate heated to 80^0C inside water for 24 hours (Mpa)	Behavior of laminate with increasing temperature	v_t
B	5 plies of woven roving	10.2	8..1	4.4	Strength decreases	0.71
C	2. plies of (42.7g) harmat ply of woven roving plies of (softmat)	2.7	4.1	4.2	Strength increases	0.51
D	1 ply of softmat 2 plies of (42.7g) hardmat 1 ply of woven roving 2 plies of (42.7g) hardmat 1 ply of softmat	2.9	2.61	4.3	Strength increases	0.43
E	8 plies of (42.7g) hardmat	4.4	4.0	2.2	Strength decrease	0.45
F	2 plies of softmat 4 plies of (42. 7g) hardmat 2.plies of softmat	4.0	5.2	5.1	Strength increases	0.25
G	12 plies of softmat	5.9	4.6	4.5	Strength decreases	0.33

A careful study of the above tables 2 to 4 clearly reveal the spectacular behaviour of specimens C , D and and their habit of increasing in strength with exposure to higher than room temperatures. This spectacular behaviour can be seen spanning the entire three different tests: tensile, hardness and bending. Similarly, specimens B, E and G belong to their own group. As these specimens become subjected to higher temperatures, their strengths begin to fail. Taking specimen B as a particular example, even though it has the highest fibre volume fraction, V_r, the strength decreases as the temperature increases. The entire three different tests also confirm this behaviour. Hence, the behaviour of the specimens as discovered above cannot be said to have occurred by accident. neither can it be classified as experimental error. Also with the three different tests occurring in three different orientations: bending. tension and indentation, it cannot, however, be said to be influenced by the fibre directions in the laminates. Note also the way dry, wet and room temperature condition have been employed in the experiments. Consequently, in the design and lamination of pressure vessels, pressure pipes, speed boats, driers. etcetera preference must be made for such group of laminates such as specimens B, D and F rather than B. E and G. However, there is nothing yet to prove that such properties involving increasing strengths with increasing temperatures will still be in progress at much higher than temperature ranges already shown.

CONCLUSIONS

From the experimental results so far, we can now safely conclude that:

1. Certain reinforcements combination in handlay- up of E-glass exhibit the properties of increasing strength with increasing temperature
2. As a result of this property, such laminates can be used in much wider range of temperature conditions than ever before and so higher margin of safety and durability in operation achieved.

3. This is indicative of the fact that improvement in the strength of laminates employed for use under elevated temperature conditions such as in peedboats, pressure pipes and pressure vessels can be achieved by careful combination of glass reinforcements during lamination.

REFERENCES

1. Warren. R.1989. "Composites Research and Development of High Temperature Materials for Industry". Proc. Conf. Commission of the European Communities, Elsevier, pp. 153-167

2. James D. L. and Black, W.Z., 1996, "Thermal Analysis of continuous filament wound composite". *Journal of thermoplastic composite material*, Technical Publications Company Inc. 9(I). pp. 54 - 57.

3. Aveston J., Kelly, A and Sillwood, J.M., 1980. Proceedings of ICCM 3 (Paris). "Advances in Composite Materials", (Pergamon, Oxford) I.pp. 556 - 568.

4. Tsai, SW., 1965, "Strength Characteristics of Composite Materials". NASA CR. 224.

5. Haga. O., Koyama, Hand Kewada, K., 1996, "Mechanical Properties of a new super-hybrid material". International *Journal of material Science and Engineering.* Published by VSPBV, 5(2), page 139.

6. Edelugo, S. O. and Enetanya. A.N., 2001, "Effect of Directional Chance Agreement of Fibres Over and Above the Traditional Fibre Volume Fraction Dependence of Composite Strength". *Global Journal of Mechanical Engineering.*, 2(I), pp. 74-75

EXPERIMENTAL TEST RESULTS, TABLES A D PLOTS REFERRED TO IN THE TEXT.

Material Specimen B **Dimension:** Width Thickness Length22.82mm 5.53mm 300mm
Composition: 5 plies of woven roving
Lamination Method: Handlay-up of E-glass in polyster resin
Treatment: Nil
Test: Tensile Test
Fibre Volume Fraction: $V_1 == 0.71$ Cross

sectional area = 126.195 x -10^{-6} m^2

			10^{-3}	
15,200	8.2	108.6	27.3 x 10^{-3}	
16,800	8.8	120.0	29.3 x 10^{-3}	120.0

Table 5: Experimental Results of Specimen 'B' (Tensile Test: Untreated Specimen)

Applied Force (N)	Extension (mm)	Stress (Mpa)	Strain	Ultimate Strength (Mpa)
1,000	1.0	7.9	3.3 x 10-^{3}	
2,000	1.7	15.8	5.7 x 10-^{3}	
3,400	2.4	26.9	8.0 x 10-^{3}	
4,500	2.9	35.3	9.7 x 10-^{3}	
6,000	3.5	47.6	11.7 x 10-^{3}	
7,400	4.1	58.6	13.7 x 10-^{3}	
8,900	4.6	70.5	15.3 x 10-^{3}	
10,400	5.1	82.4	17.0 x 10-^{3}	
11,250	5.4	89.1	18.0 x 10-^{3}	
13,400	6.0	106.2	20.0 x 10-^{3}	
14,800	6.6	117.3	22.0 x 10-^{3}	
16,800	7.3	133.1	24.3 x 10-^{3}	133.1

Material Specimen B Dimension Width Thickness Length 25.3rnm --5.53rnlll -300mrn
Composition: -5 plies of woven roving
Lamination -Method: -Handlay-up -or E-glass -In Polyster resin
Treatment: Healed, inside Water at 80°C for 24 hours
Test: -Tensile Test
Fibre Volume Fraction: V_f = 0.71 -Cross Sectional Area = *139.9* x 10^{-6} m^2

Table 6: --Experimental Result s of Specimen -'B' (Tensile Test:
Heated inside water at 80^{0}C for 24 hours)

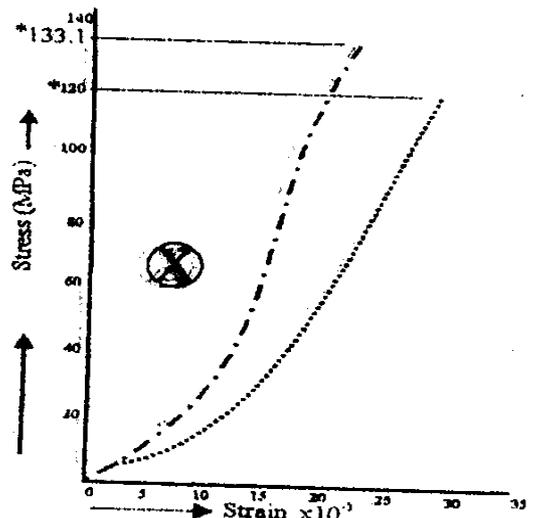| Applied Force (N)	Extension (mm)	Stress (Mpa)	Strain	Ultimate Strength (Mpa)
500	0.7	3.6	2.3 x 10-^{3}	
1,450	1.9	10.6	6.3 x 10-^{3}	
2,350	2.8	16.8	9.3 x 10-^{3}	
3,800	3.6	27.1	12.0 x 10-^{3}	
5,300	4.4	37.9	14.7 x 10-^{3}	
7,000	5.2	50.00	17.3 x 10-^{3}	
8,500	5.8	60.7	19.3 x 10-^{3}	
10,000	6.4	71.4	21.3 x 10-^{3}	
11,900	7.1	85.0	23.7 x 10-^{3}	
13,800	7.8	98.6	26.0 x	

Fig. I. Graphic presentation or specimen 'B' (Tensile Test) plotted from the same origin
………..Untreated specimen
-----------Heated inside water at 80^{0}C for 24hrs
   * crushing strength
   ⊗ analysis graph

Material Specimen C Dimension Width Thickness Length 20mm 4.5mm 300mm
Composition: Two poles of (42.7g) hardmat One ply of woven roving
Two plies again of (42.7g) hardmat
Lamination Method: Handlay-up of E-glass in polyster resin
Treatment: Nil
Test: Tensile Test
Fibre Volume Fraction: V_f = 0.51 Cross sectional area = 90 x 10^{-6} m^2

Table 7: experimental result of specimen 'C" (tensile test: untreated specimen)

Applied Force (N)	Extension (mm)	Stress (Mpa)	Strain	Ultimate Strength (Mpa)
850	1	9.4	3.3 x 10-^{3}	
1,280	1.4	14.2	4.7 x 10-^{3}	
1,800	1.8	20.0	6.0 x 10-^{3}	
2,800	2.4	31.1	8.0 x 10-^{3}	
3,300	2.8	36.7	9.3 x 10-^{3}	
4,350	3.35	48.3	11.2 x	

			10^{-3}	
5,270	3.85	58.6	12.8 x 10^{-3}	
5,750	4.3	63.9	14.3 x 10^{-3}	63.9

Material Specimen C Dimension:

Width Thickness Length 20mm 4.5mm 300mm

Composition: 2 plies of (427g) hardmat I ply of woven roving 2 plies again of (42.7g) hardmat

Lamination Method: Handlay-up of E-glass in polyster resin

Treatment: Heated, inside water at 80°C for 24 hours

Test: Tensile Test

Fibre Volume Fraction: $V_1 = 0.51$ Cross sectional area = 90 x 10^{-6} m^2

Table 8: Experimental results of specimen 'C'' (tensile test: heated inside water at 80°C for 24 hours)

Applied Force (N)	Extension (mm)	Stress (Mpa)	Strain	Ultimate Strength (Mpa)
400	0.5	4.4	1.7 x 10^{-3}	
750	1.25	8.3	4.2 x 10^{-3}	
1,250	2.2	13.9	7.3 x 10^{-3}	
1,850	3	20.1	10.0 x 10^{-3}	
2,320	3.5	25.8	11.7 x 10^{-3}	
3,250	4.5	36.1	15.0 x 10^{-3}	
3,800	5	42.2	16.7 x 10^{-3}	
4,230	5.3	47.0	17.7 x 10^{-3}	
5,270	6.28	58.5	20.0 x 10^{-3}	
6,200	6.85	68.9	22.8 x 10^{-3}	
7,100	7.48	78.9	24.9 x 10^{-3}	78.9

Material Specimen D Dimension: Width Thickness Length

20mm 6mm 300mm

Composition: One ply of softmat Two plies of (42.7g) hardmat One ply of woven roving Two plies again of (42.7g) hardmar One ply again of softmat

Lamination Method: Handlay, up of E-glass in polyster resin

Treatment: Nil

Test: Tensile Test

Fibre Volume Fraction: $V_1 = 0.43$ Cross sectional area = 120 x 10^{-6} m^2

Table 9: experimental results of specimen 'D' (Tensile Test: Untreated Specimen)

Applied	Extension	Stress	Strain	Ultimate

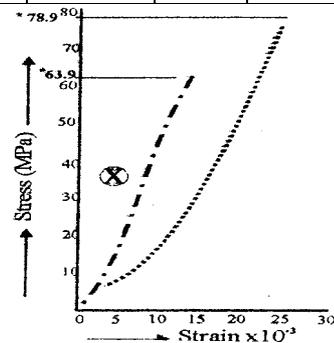| Force (N)	(mm)	(Mpa)		Strength (Mpa)
600	0.5	0.5	1.7 x 10^{-3}	
1,000	1.18	8.3	3.9 x 10^{-3}	
1,460	1.6	2.2	5.3 x 10^{-3}	
2,000	2	16.7	6.7 x 10^{-3}	
2,450	2.25	20.4	7.5 x 10^{-3}	
3,450	3.75	28.8	9.2 x 10^{-3}	
3,900	3.0	32.5	10.0 x 10^{-3}	
4,450	3.3	37.1	11.0 x 10^{-3}	
5,450	3.75	45.4	12.5 x 10^{-3}	
6,600	4.2	55.0	14.0 x 10^{-3}	55.0

Fig.2. Graphic presentation of specimen 'C' (Tensile test) plotted from the same origin …………..Untreated specimen

-----------Heated inside water at80°Cfor 24hrs

     *crushing strength

     ⊗ analysis graph

Material Specimen D **Dimension** Width Thickness Length   20mm 6mm 300mm

Composition: One ply of softmat Two plies of (42.7g) hardmat One ply of woven roving Two piles again of (42. 7g) hardmat One ply again of softmat

Lamination Method: handlay, up of E-glass in polysler resin

Treatment: Heated, inside water at 80°Cfor 24 hours

Test: Tensile Test

Fibre Volume Fraction: $V_1 = 0.43$ Cross sectional area = 120 x 10^{-6} m^2

Table 10 Experimental Results of Specimen 'D' (Tensile Test: Heated inside water at 80°C for 24 hours)

Applied Force (N)	Extension (mm)	Stress (Mpa)	Strain	Ultimate Strength

				(Mpa)
600	0.5	0.5	1.7 x 10^{-3}	
1,550	1.3	12.9	4.3 x 10^{-3}	
2,450	2	20.4	6.7 x 10^{-3}	
2,940	2.25	24.5	7.5 x 10^{-3}	
4,000	2.81	33.3	9.4 x 10^{-3}	
4,450	3	37.5	10.0 x	

			10^{-3}	
5,400	3.5	45.0	11.7 x 10^{-3}	
6,850	4.15	57.1	13.8 x 10^{-3}	
7.550	4.6	65.4	15.3 x 10^{-3}	
9,350	5.2	77.9	17.3 x 10^{-3}	77.9
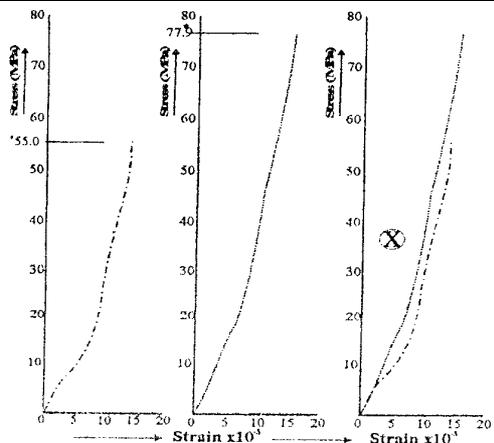
Fig. 3 Graphical Presentation of Specimen "D" (Tensile Test)
— · — Untreated specimen
········· Heated, inside water at 80°C for 24 hours
· Crushing Strength
Ⓧ Analytical graph
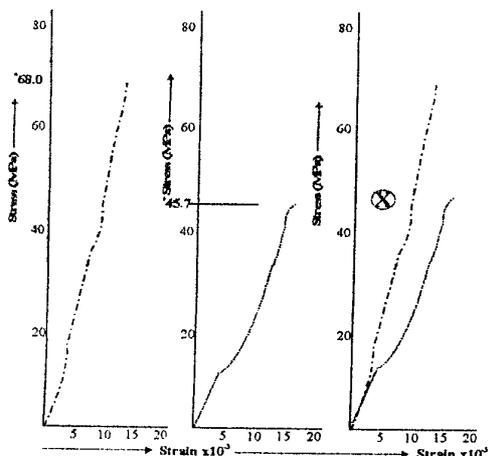
Fig 4. Graphical presentation of specimen "E" (Tensile Test) Plotted from the same origin
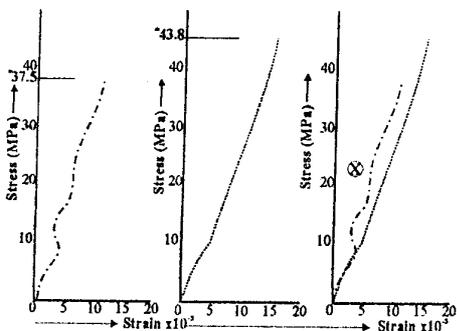
F.g 5 Graphical Presentation of Specimen "F" (Tensile Test)
— · — Untreated specimen
········· Heated, inside water at 80°C for 24 hours
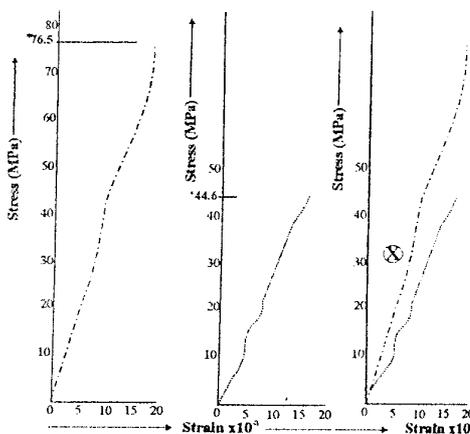
Fig. 6 Graphical Presentation of Specimen "G" (Tensile Test)
— · — Untreated specimen
········· Heated, inside water at 80°C for 24 hours
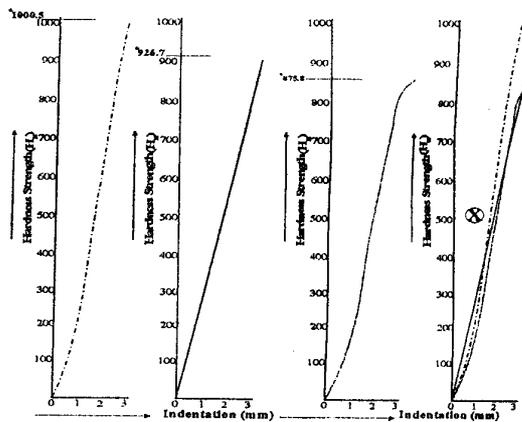
Fig. 7 Graphical Presentation Specimen "B" (Hardness Test)
— · — Untreated specimen
········· Heated, at 60°C (dry) for 24hours
········· Heated, inside water at 80°C for 24 hours
· Crushing Strength
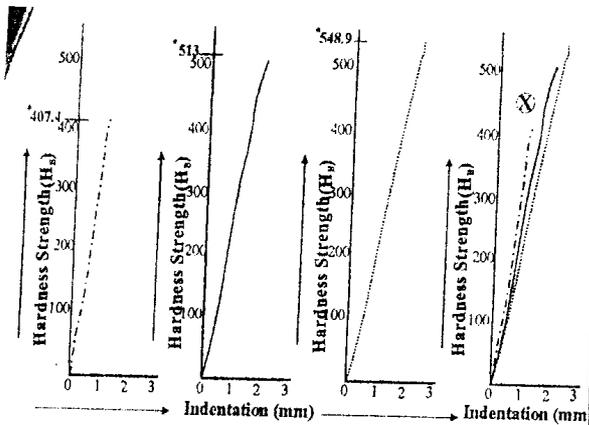
Fig.8 Graphical Presentation Specimen "C" (Hardness Test)

-·-·- Untreated specimen
——— Heated, at 60°C (dry) for 24hours
········ Heated, inside water at 80°C for 24 hours
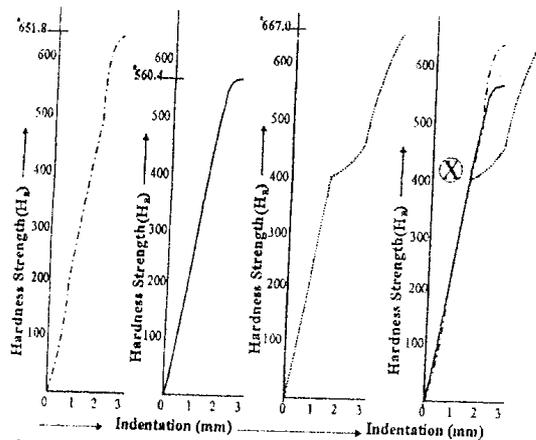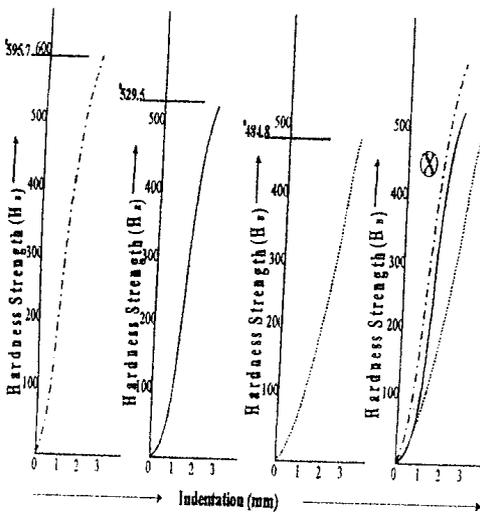* Crushing Strength
Ⓧ Analytical graph

Fig.9 Graphical Presentation Specimen "D" (Hardness Test)

-·-·- Untreated specimen
——— Heated, at 60°C (dry) for 24hours
········ Heated, inside water at 80°C for 24 hours

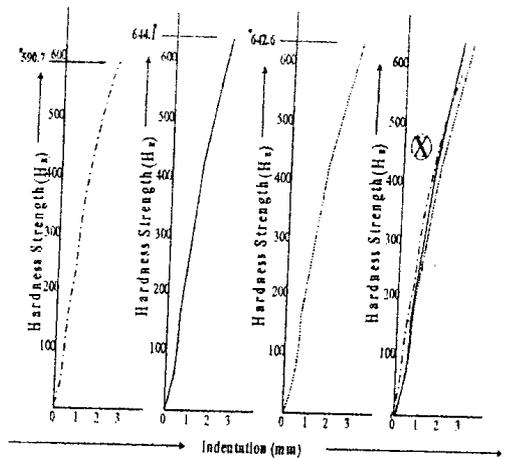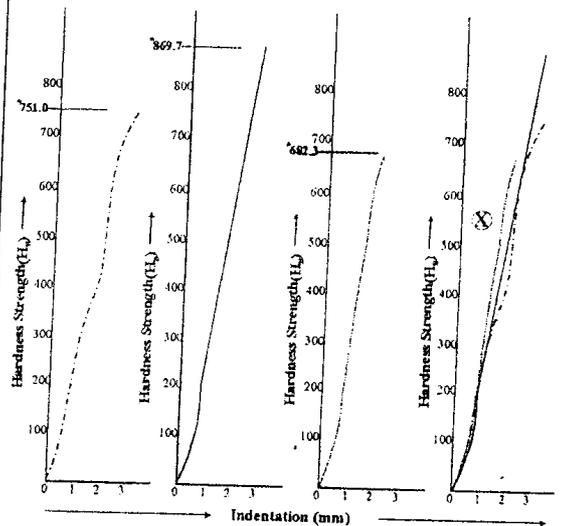Fig. 10 Graphical Presentation of Specimen "E" (Hardness Test)

Fig. 11 Graphical Presentation of Specimen "F" (Hardness Test)

-·-·- Untreated specimen
——— Heated, at 60°C (dry) for 24hours
········ Heated, inside water at 80°C for 24 hours

Fig. 12 Graphical Presentation of Specimen "G" (Hardness Test)

-·-·- Untreated specimen
——— Heated, at 60°C (dry) for 24hours
········ Heated, inside water at 80°C for 24 hours
* Crushing Strength
Ⓧ Analytical graph

-·-·- Untreated specimen
——— Heated, at 60°C (dry) for 24hours
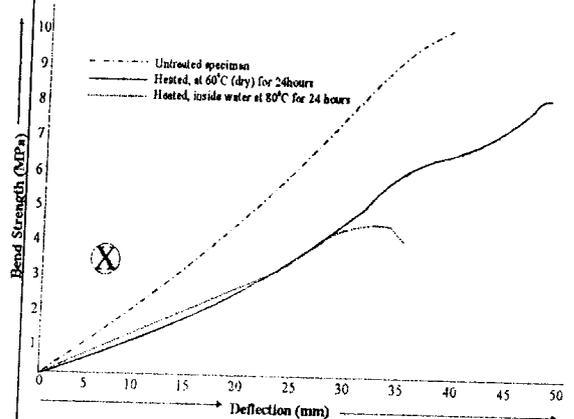········ Heated, inside water at 80°C for 24 hours

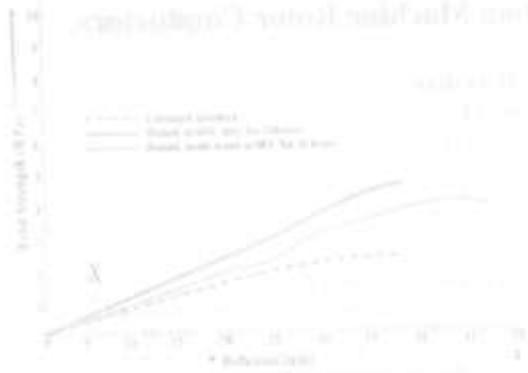Fig. 13 Specimen "B" (Bending Test) plotted from the same origin

Fig. 14 Specimen "C" (Bending Test) plotted from the same origin

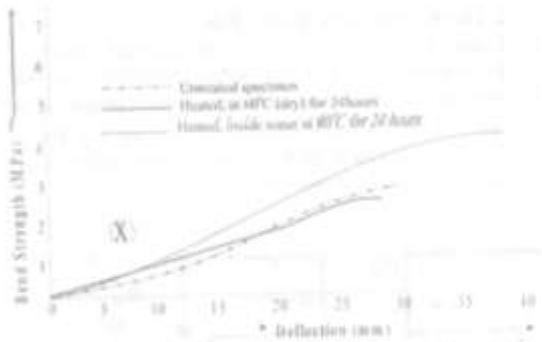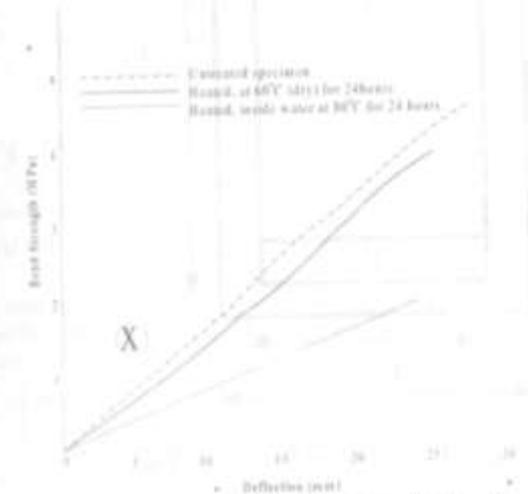Fig.15 Specimen "D" (Bending Test) plotted from the same origin

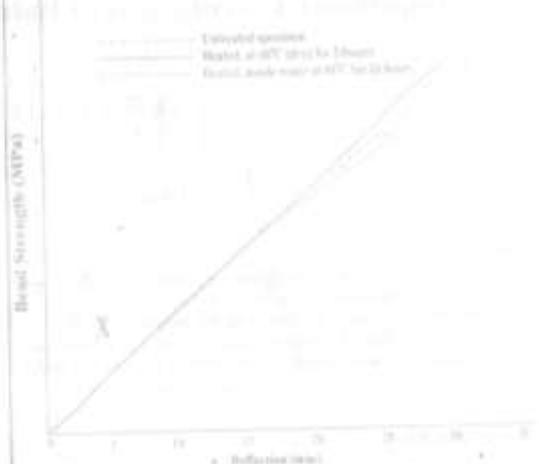Fig. 16 Specimen "E" (Bending Test) Plotted from the same origin

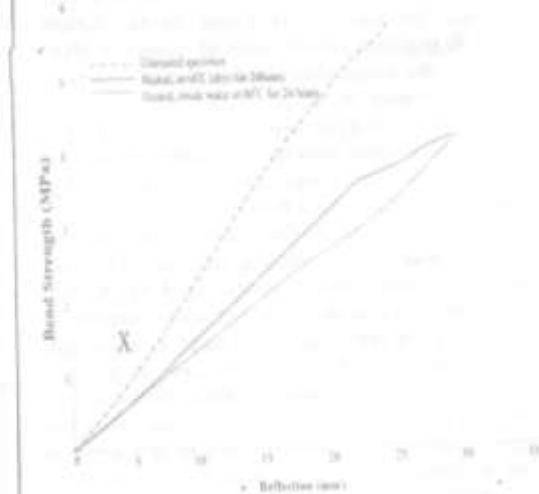

Fig. 17 Specimen "F" (Bending Test) Plotted from the same origin

Fig. 18 Specimen "G" (Bending Test) Plotted from the same origin