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Research Article

Effect of Coating on Strength Degradation of GFRP Composite Materials

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Abstract

Fibre composites are being used in various applications like aerospace, military, marine boats and submarine. The reinforcement materials are highly hygroscopic; the matrix material provides protection to the reinforcement. When the edges of composite materials parts made of are exposed to environment, water molecules passes along the reinforcement. This leads damage to the interfacial bonding and affects the performance of the composite laminate. It is necessary to perform mechanical and environmental characterization to enhance their application spectrum. Therefore, the investigation has been carried out for the strength deterioration of uncoated and coated GFRP composite laminates under different environmental conditions and estimated the effect of coating on strength degradation of the material. From the experimental results and mathematical analysis painted GFRP laminates shows small changes in mechanical properties compared to unpainted GFRP laminates.

Keywords: *The Resin transfer moulding; Glass fibre reinforced polymer; Three-point bending test; Flexural modulus; retention ratio.*

1. Introduction

Fibre reinforced polymer (FRP) composite materials are low cost, light-weighted, and have good mechanical properties and thus have the potential for the use of them in structural applications such as chemical plants, pipelines blades for wind turbines, construction structures, boat hulls, automobile and aerospace industry etc. which are subjected to aggressive environment. The study of the exposure of such materials subjected to different environment under varying temperature, humidity conditions, etc. is of outmost importance, in order to assess the impact of these t ageing factors on their mechanical behavior. As far as water is concerned, absorption of moisture particle has been take place through polymer matrices (Zhang et al. (2000)) and its effect is detrimental for certain material properties. For example, absorbed water has been found to spoil the interfacial bonds (Papanicolaou et al. (2006), Adamson (2004)) which cause changes in the overall free matrix volume. The latter can lead to accumulation of hydroscopic stresses that can find and fail the resin.

With reference to the work related to influence of resin chemistry on water uptake and environmental ageing in glass fibre reinforced composites-polyester and vinyl ester laminate may cause hydrolysis and physical ageing. The chemical composition of the resin appears to affect the equilibrium content of water and affects the mechanical performance; the larger the water content leads to the greater swelling stresses (Schutte (1994), Gates and Grayson (1998)). Providing coating on the surface of the material, the swelling stresses will be reduced. This experience depends on the chemical structure of the resin, the temperature and the total period of exposure to water (Boinard *et al.* (2000), Liu *et al.* (2012)). In connection of the experimentation, the thickness of the film coating influences the bonding quality of the glass material. The environmental stress cracking failure due to temperature and moisture has been studied by using single E-glass filaments for glass fibre reinforced composites (Jones et al. (1983). The mechanical behavior of polymer composites under the influence of extreme and complex conditions (Mula et al. (2006)) evaluated. They observed the variations in mechanical properties during aging process. Tests were carried out on carbon fiber reinforced polymer (CFRP) bonded to concrete. The test results indicated that the presence of water during the CFRP application, the bond quality has decreased and most of the resulting failures were seen in adhesive failures along the primer/concrete interface (Wan et al. (2006)). Nishizaki and Kishima, (2007) focused on different environmental conditions on GFRP and tested using tensile test. The test results showed that the tensile strength was affected at different levels of environmental conditions for various exposure periods. Mouzakis et al. (2008) studied on the different types of FRP laminates produced using the wet lay-up technique and exposed to different environments. The results showed a significant loss of strength and ultimate strain for glass FRP, but hybrid glass-carbon laminates showed very little loss of mechanical properties.

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The objective of this work is investigation on strength deterioration of GFRP composite laminates and effect of coating under different environmental conditions, also estimated life the materials by mathematical analysis. For this number of specimens are prepared, some of specimens are exposed to accelerated hydrothermal environmental conditions and some of specimens are painted or coated with resin and exposed to same conditions. For this series of experiments are conducted and results are interpreted to know behavior of the materials.

2. Experimental Methodology

2.1 Production of laminates using Resin transfer molding

The materials used for GFRP laminates are polyester resin with density 1.35 g/cm^3 and glass fibre mats of woven fabric glass fibre with density 450 g/cm^3. The laminates were produced by mixing 60% of polyester resin and 40% of glass fibre using Resin transfer moulding (RTM) machine as shown Fig.1.The parameters considered in RTM for producing the laminates were (i) injection pressure range of 30-40 Psi (ii) curing temperature – room temperature. The laminate was removed from the RTM mould with dimensions of 300mm X 300mm X 8mm and sliced to test samples according to ASTM-D-638 standard with dimensions of $250\ mmX\ 30\ mm\ X\ 8mm$ as shown Fig.2.

The glass fibre mats were placed in-between the mould plates and clamps. The resin was mixed with 2% of accelerator (cobalt nathylene) and 2% of catalyst (methyl ethyl keypricperoxide) then poured into the cylinder through the valve. The valve was closed immediately then air pumped into hollow cylinder such that pressure should reach 40 Psi. The bottom valve of the cylinder was slowly released so that pressurized chemical resin enters in to the mould and it has to spread equally in to all directions.

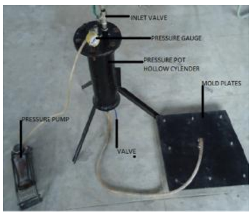

Fig. 1 Resin transfer molding machine

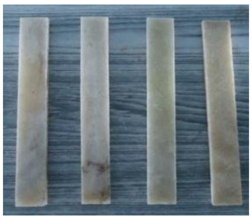

Fig.2 GFRP Laminate Test Pieces

The laminates were kept for 4 to 5 hours idle time in the mould to get required shape. After curing the laminate, the mould was unsealed and separated the lower and upper mould parts. The laminate was removed from the mould then sliced into test samples as shown Fig. 2.

2.2 Testing of the Laminates

Some of the unpainted and painted specimens thus prepared are exposed in water at room temperature for 180 days and some of them (uncoated & coated) are exposed to constant temperature (60° C) in water bath tub for period of 60 days. At every 30 days few specimens are taken from water bath at room temperature and at every 10 days few specimens are taken from constant temperature water bath tub for mechanical testing. Flexural properties are evaluated by conducting three point bending test. From the test results drawn load deflection curve and calculate the flexural modulus using formulae

$$E_f = \frac{L^3 m}{4bd^3} \qquad 1$$

Where E_f = Flexural modulus; L = Support span (Specimen gauge length) in mm; b = Width of specimen in mm; d = Depth or thickness of specimen in mm and m = the gradient of the initial straight-line portion of the load deflection curve in N/mm.

3. Results and Discussions

3.1 Results of three point bending test

Specimen dimensions as per the standard ASTM-D-790: Length of Specimen =250 mm, Specimen support Length=220 mm, breadth b=30 mm, Thickness h=8 mm

3.1.1 Three point bending test-Uncoated Specimens exposed in water at room temperature:

The numbers of uncoated specimens of dimensions $250mmX\,30mmX\,8mm$ are exposed to water at room temperature and same tested with three point bending test. This was repeated for every 30 days interval and the results are noted and the same was plotted in Fig. 3. From the Fig flexural modulus was calculated and shown in Table.1 (Annexure).

3.1.2 Three point bending test -Coated Specimens exposed in water at room temperature:

The numbers of coated specimens of dimensions $250mmX\,30mmX\,8mm$ are exposed to water bath at room temperature, and same tested with three point bending test. This is repeated for every 30 days interval and the results are noted and the same was plotted in Fig 4. From the Fig flexural modulus was calculated and shown in Table.1 (Annexure).

3.2.1 Three point bending test - Uncoated Specimens exposed in water at constant temperature 60°C:

The numbers of uncoated specimens of dimensions $250mmX\,30mmX\,8mm$ are exposed to water bath at constant temperature 60°C, and same tested with three point bending test. This is repeated for every 10 days interval and the results are noted and the same was displayed in the Fig 5. From the Figs flexural modulus was calculated and shown in Table.1 (Annexure).

3.2.2 Three point bending test - Coated Specimens exposed in water at constant temperature 60°C:

The numbers of coated specimens of dimensions

$250mmX\,30mmX\,8mm$ are exposed to water bath at constant temperature 60°C, and same tested with three point bending test. This is repeated for every 10days interval and the results are noted and the same was displayed in the Fig 6. From the Figs flexural modulus was calculated and shown in Table.1 (Annexure).

3.3 Performance Prediction Analysis

An indirect indication of service life is obtained simply by comparison of the performance of materials under given test conditions, the one which shows the smaller change being deemed to perform better. To make a direct estimate of service life of materials, it is necessary to apply some form of extrapolation technique to their experimental data. The life estimation of GFRP Composites in these environmental conditions are analyzed by employing exponential linear regression analysis life prediction mathematical models. The life predication equation was derived on the basis of experimental data in terms of the degradation coefficient (decay constant), soaking time, minimum strength and exponential coefficient for different environmental conditions. Exponential linear regression provides powerful technique for fitting the best relationship between dependent and independent variables based on this technique life estimation of composite materials was being established as follows.

$$Y(X) = Yo + A1\exp - (x - xo)/t1;$$

Here Y (x) is dependent parameter
'X' is exposure time in terms of days
'Y_0' is minimum strength property after long exposure of time 't_1' is the degradation coefficient or decay constant
A_1 is Exponential coefficient which was determined by using experimental data

The GFRP composite materials exposed in water at room temperature and constant temperatures, 60^0 C the mathematical equations for flexural modulus was established by experimental data are given in equations 2, 3, 4 and 5 and also represented as shown in Fig.7-10.
The life prediction equation at room temperature for unpainted specimen is

$$Y(x_i) = 3.7729 + 7.8896 exp - (x_i - 11.8072)/111.1293 \ldots\ldots(2)$$

The life prediction equation at room temperature for painted specimen is

$$Y\ (x_i) = 5.8647 + 6.6623 exp - (\mathbf{x_i})/57.3143 \ldots\ldots\ldots\ldots.(3)$$

At const. temperature60 ^{0}C life prediction equation for unpainted is

$$Y(x_i)\ = 2.12489 + 3.6956 exp -\ (x_i - 9.315224)/62.251 \ldots\ldots.(4)$$

At const. temperature60^{0}C life prediction equation for painted is

$$Y\ (x_i) = 5.3202 + 1.74744 exp - (x_i - 6.91233)/28.6286 \ldots\ldots...(5)$$

By using above equations calculated the predicted values of flexural property and compare with experimental values as shown table 2(Annexure).

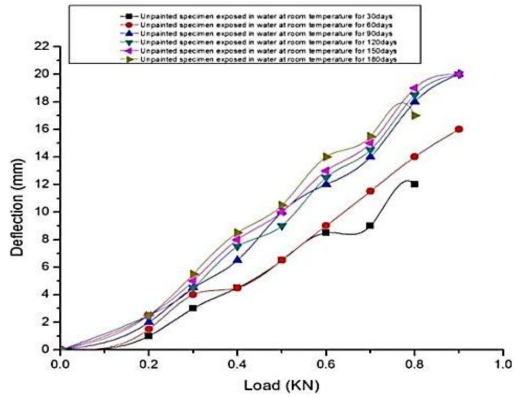

Fig. 3 Uncoated Specimen exposed in water at room temperature (30 to 180 days)

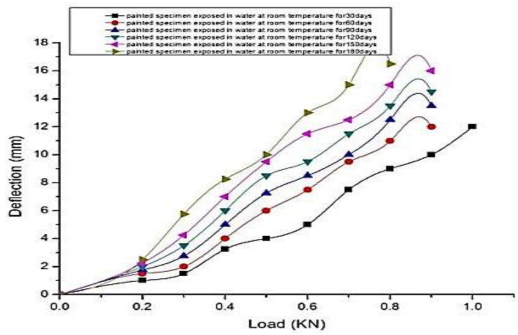

Fig. 4 Coated Specimen exposed in water at room temperature (30 to 180 days)

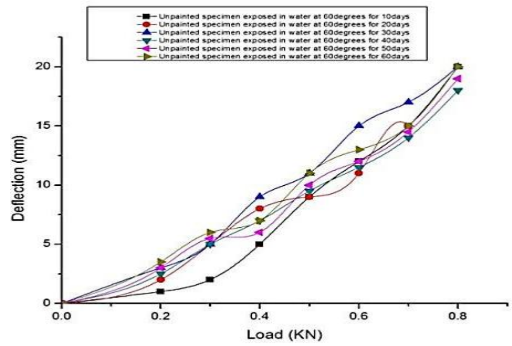

Fig. 5 Uncoated Specimen exposed in water at 60°C (10 to 60 days)

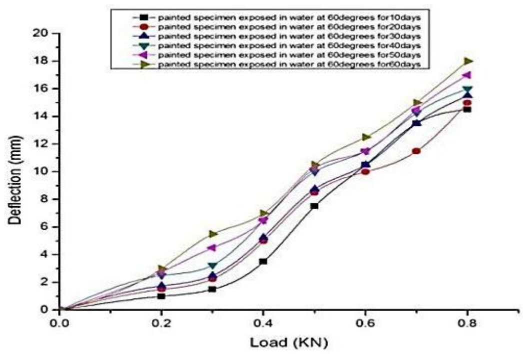

Fig. 6 Coated Specimen exposed in water at 60°C (10 to 60 days)

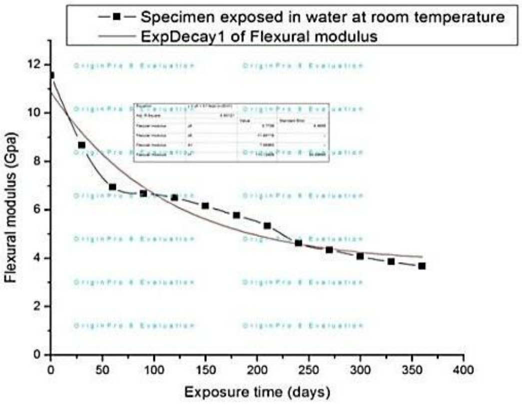

Fig. 7 The mathematical modeling for GFRP uncoated specimen exposed at room temperature

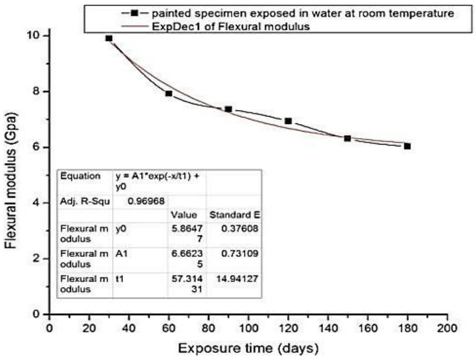

Fig. 8 The mathematical modeling for GFRP coated specimen exposed at room temperature

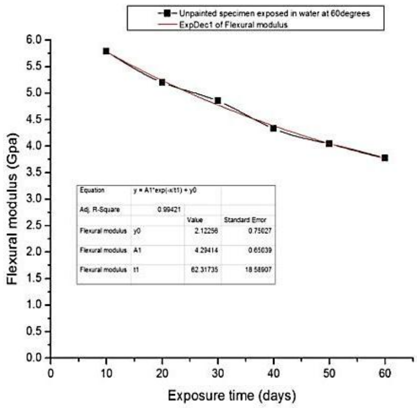

Fig. 9 The mathematical modelling for GFRP uncoated specimen exposed at 60°C

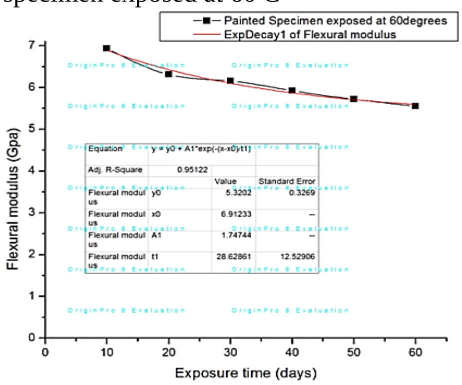

Fig. 10 The mathematical modeling for GFRP Coated specimen exposed at 60°C

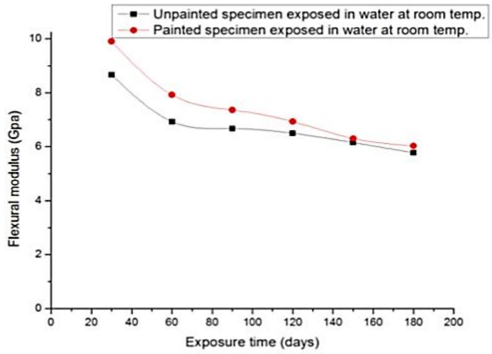

Fig. 11 Flexural modulus v/s Exposure time for specimens exposed in water at room temperature

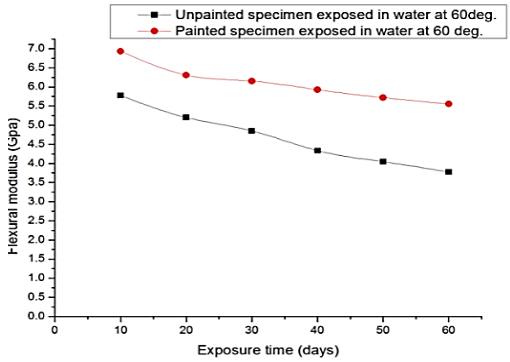

Fig. 12 Flexural modulus v/s Exposure time for specimens exposed in water at 60°C temperature

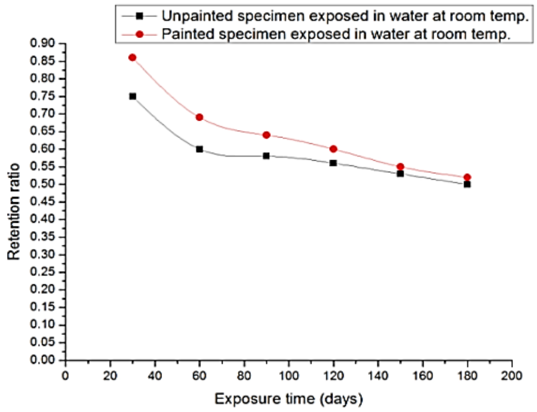

Fig. 13 Retention ratio v/s Exposure time for specimens exposed in water at room temperature

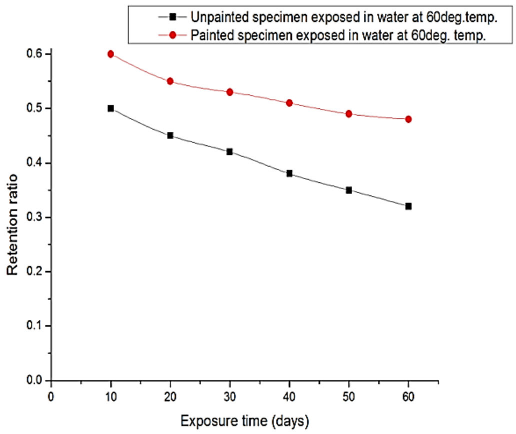

Fig. 14 Retention ratio v/s Exposure time for specimens exposed in water at 60°C temperature

3.4 Discussions

The GFRP (E-Glass/Polyester) uncoated and coated test samples were subjected to aging in water at room temperature for 180days and at 60°C constant temperature for 60days respectively, and tested with three point bending test, the results are noted and displayed in Fig 3-6. From the test results rapid reduction in mechanical properties is observed in uncoated specimens and gradual decrease is observed in coated specimens over the exposure time as shown Fig 11 and 12. As per the experimental results of uncoated and coated specimens exposed in water at constant temperature 60^0C, the strength degradation (Flexural modulus) is more in uncoated samples. The retention ratio (ratio of flexural modulus of exposed specimen to unexposed specimen) has been calculated for flexural modulus and presented in Fig13 and 14 that shows decreases in the painted specimen compared with unpainted specimen. From the results of uncoated (unpainted) and , coated (painted) specimens exposed in water at room temperature, initially strength appear to be rapidly decrease then gradually decreased as soaking(exposure) time is increasing this is because of cross linking reaction in polyester resin is still in progress up to 2 weeks of laminate preparation. By comparing the test results of coated(same GFRP material coated on edges and surfaces with polyester resin) and uncoated specimens exposed at room temperature and elevated temperature, coated (painted)specimens shows positive results because less moisture induced at the interference of fibre matrix. The samples subjected to aging at the constant temperature water bath (60º C) showed a hyperbolic decrement in the flexural strength. On the whole it was observed that less reduction of flexural modulus in coated specimens when compared to the uncoated (unpainted) specimens with the presence of moisture and temperature. There is significant reduction in modulus because of loosing bonding strength of the polyester resin at temperature. It is clear that the modulus rapidly decreases due to hygrothermal aging because moisture generally affects any property which is dominated by the matrix and/or interface.

The regression analysis is performed for each of the time steps and this yields a set of exponential linear relationships between the flexural modulus and exposure time at room and constant temperatures were developed as shown in fig 7 and 8. The relationships so obtained are shown in equations 2, 3, 4 and 5 can be used to determine the flexural modulus of the composite material at different time steps under different conditions. For predictions of response due to immersion in water at room temperature and 60°Cas (shown fig.9 and 10)the values of flexural modulus at each time step are obtained by substituting the exposure time in days in the equations 2,3,4 & 5, the values are listed in Table 2 (Annexure). The relation between the experimental and predicted values and life the material was estimated from the data as shown in Table2 (Annexure).

The prediction values of flexural modulus, for the specimens immersed in water at room temperature and 60°C slightly variation was observed at room temperature and higher variation at elevated temperatures when compared to the experimental values. It has to be noted that as temperature increases the predicted values are increases that indicate rate of degradation increase. The life estimation of composite materials is possible with prediction models.

4. Conclusions

The investigation showed a remarkable reduction in mechanical strength (flexural modulus of coated and uncoated specimens) of GFRP composite laminates which are subjected to different environmental conditions over exposed time. The flexural strength values of the uncoated specimens are rapidly decreased when compared to coated specimens over exposure period of 180 days in water at room temperature and 60 days in water at 60^0C constant temperature. As per the test results the retention ratio for the painted specimens exposed at room temperature was about 0.86 to 0.52 but in case of unpainted specimens it was 0.75 to 0.50 similarly at 60^0C constant temperature it was about 0.60 to 0.43 in case of coated (painted) specimens but in case of uncoated (unpainted) specimens it was 0.50 to 0.24.This results shows that strength deterioration of GFRP composite laminates under flexural loading subjected to exposure tests. The following points drawn from test results in this study.

a). The Composite material moisture absorption is more. The presence of moisture or water particles in the matrix, fibre-matrix interface and also attack on the glass fibres are all the reason for reduction of properties due to environmental impact

b) The test results showed small changes in some mechanical properties of coated specimens as compared to uncoated specimens.

c).The flexural modulus reduction is more in hygrothermal aging because of temperature is a key factor for accelerated aging in the processes of water diffusion and chemical degradation.

d) Based on test results the surface and edge coatings have a protective against changes of mechanical properties of GFRP composite laminates which are subjected harsh environmental conditions.

e) Theoretical results are similar when compared to experimental results. Therefore life of the laminate has been estimated.

f) On the basis of the analysis the minimum strength material has been estimated.

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Annexure:

Table1: Flexural modulus and Retention ratio of GFRP laminates at different conditions

Unexposed Specimen Flexural modulus=11.553Gpa									
Specimens exposed in water at room temperature					Specimens exposed in water at 60^0C temperature				
Exposure Time in days	Uncoated specimen		Coated specimen		Exposure Time in days	Uncoated specimen		Coated specimen	
	Flexural Modulus (Gpa)	Retention ratio	Flexural Modulus (Gpa)	Retention ratio		Flexural Modulus (Gpa)	Retention ratio	Flexural Modulus (Gpa)	Retention ratio
30	8.665	0.75	9.902	0.86	10	5.7764	0.50	6.932	0.60
60	6.932	0.60	7.922	0.69	20	5.1995	0.45	6.308	0.55
90	6.672	0.58	7.365	0.64	30	4.852	0.42	6.152	0.53
120	6.499	0.56	6.932	0.60	40	4.332	0.38	5.926	0.51
150	6.157	0.53	6.308	0.55	50	4.0436	0.35	5.72	0.49
180	5.776	0.50	6.027	0.52	60	3.773	0.32	5.55	0.48

Table2: Predicted values of flexural modulus in comparison with experimental values of GFRP Composite laminates at different conditions

Flexural modulus of unpainted and painted specimens with exposure time									
Specimens exposed in water at room temperature					Specimens exposed in water at 60^0C temperature				
Exposure Time days	Uncoated specimen		Coated specimen		Exposure Time days	Uncoated specimen		Coated specimen	
	Predicted values in Gpa	Experimental value in Gpa	Predicted values in Gpa	Experimental value in Gpa		Predicted values in Gpa	Experimental value in Gpa	Predicted values in Gpa	Experimental value in Gpa
0	11.553	11.553	11.553	11.553	0	11.553	11.553	11.553	11.553
30	9.188	8.665	9.810	9.902	10	5.780	5.7764	6.882	6.932
60	7.907	6.932	8.201	7.922	20	5.238	5.1995	6.428	6.308
90	6.929	6.672	7.249	7.365	30	4.776	4.852	6.100	6.152
120	6.183	6.499	6.685	6.932	40	4.382	4.332	5.870	5.926
150	5.612	6.157	6.350	6.308	50	4.047	4.0436	5.708	5.720
180	5.177	5.776	6.152	6.027	60	3.762	3.773	5.593	5.550
210	4.845	-	6.035	-	70	3.519	-	5.513	-
240	4.592	-	5.966	-	80	3.312	-	5.456	-
270	4.398	-	5.924	-	90	3.135	-	5.416	-
300	4.250	-	5.900	-	100	2.986	-	5.387	-
330	4.137	-	5.885	-	110	2.858	-	5.367	-
360	4.051	-	5.877	-	120	2.749	-	5.353	-
390	3.985	-	5.872	-	130	2.656	-	5.343	-
420	3.935	-	5.869	-	140	2.577	-	5.336	-

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