Effect of Thermal Aging on the Mechanical Properties of Hybrid Multilayer Composite with Various Core Structure

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Abstract Steels well known for their sturdiness and long-term life expectancy; however, there are drawbacks such as it is expensive, corroded as exposed to air and difficult to be formed into shape. Hybrid composite fiberglass consists of the combination of matrix, reinforcement and core structure that are well known as cheap, non-corrosive and easy to fabricate with superior characteristic that attract in many applications including utility usage as replacing steel materials. Hybrid composite panels with two different cores (aluminum and plywood) are prepared by hand lay-up method and treated at various temperature 60, 90, 120, and 150 °C. Hybrid composite fiberglass with Aluminum core observed good mechanical properties compared to plywood in the properties of flexural strength, impact and moisture resistant. Flexural strength for both Plywood and Aluminum show significant p values, meanwhile p values for strain in Aluminum observed more significant compared to plywood. Both plywood and aluminum observed significant p values in moisture test and impact strength as temperature increases. However, tensile and hardness properties show lower significant p values, R and R-square value at increasing temperature.

Keywords Thermal aging · Composite · Core structure · Mechanical properties

1 Introduction

Composite is a heterogeneous material consisting of two or more solid phase materials that increase the properties of the material rather than the individual component properties. Composite additionally offers various preferences over conventional material such as resistance to chemicals, thermal and electrical insulation properties. The demand of structural composite as an alternative to replace metals in automotive, aircraft, marine and building industries is due to its easy fabrication, high

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strength to weight ratio, lightweight and corrosion resistant [1]. Structural composite is expected to withstand various operational condition related to humidity and temperature. The combination effect of long term loading and environment surrounding can provide harmful effect toward hybrid composite mechanical strength and properties. In general, exposure to lower and elevated temperature lead to brittle behaviour and degradation of mechanical properties (cracking, chalking and flaking) of polymer respectively [2]. It is in need to design composite polymer structure that can sustain the great environment diversity such as large variation of temperature and moisture. Combination of unsaturated polyester and fibreglass composite have a strength that is dependent to the mechanism of load transfer at the interphase and the adhesion strength between the fibre and the polymer matrix [3]. However the properties also can be varied due to the change in matrix, loading condition, microstructure and environment condition (temperature, moisture and corrosive environment) [4]. Buck et al. [5] reported that the combination of moisture and sustained load at elevated temperatures causes a significant decrease in the ultimate tensile strength of E-glass/vinyl-ester composite materials. Thermal aging is a slow and irreversible alteration of a material chemical or physical structure. This alteration has normally a detrimental effect on the material properties. It leads to gradual loss of the design function and ultimate failure or unacceptable loss of efficiency. So basically, thermal aging is the process of irreversible change in the properties of polymers under the action of heat. The key factor in this aging process is thermal which lead to the alterations of the properties of the polymer itself. Aging can occur during storage or treatment of polymers. Aging is caused by chemical transformations of micro molecules, which lead to the degradation of the macromolecules and the formation of branch or structure. The rate of aging depends on the sensitivity of polymer itself. The composite fibreglass in four layers system reported obtained maximum tensile strength (250 MPa) and impact (160 kJ/mm^2) at temperature 90 °C [6]. Laoubi et al. [7] also observed in four layers of composite fibreglass the tensile and flexural strength increased at temperature below 100 °C and dramatically dropped once treated above 200 °C. Impact strength of composite fibreglass reported to have increased in impact strength until temperature 90 °C and then decreased as the temperature increased [6]. Similar finding reported by Elahi et al. 2014 with optimum value for tensile, impact and hardness at 90 °C with 200 MPa, 150 kJ/mm^2 and 55 BHN respectively [8]. Belaid et al. [9] reported that thermal aging is strongly affecting the mechanical properties of polyester fibreglass composite. The Young modulus and stress recorded decreased due to thermal aging effect treated at 80 °C in various periods of time. Similar observation reported for polyester composite fibreglass untreated and treated for 1 h at range of temperature 60–150 °C [10]. Visco, 2011 reported that polyester that is commonly used in marine field immersed in seawater and conducted accelerated aging test at 60 °C. They observed that polyester resin has high degradation compare to other vinyl ester due to different network organization [11]. The water absorption test was also reported increase due to penetration and diffusion of water molecule within polyester composite fibreglass [10]. Moisture absorption was also reported influenced by temperature and time of experimentation. Higher temperature induces greater diffusion and results in higher percentage of moisture absorbed and achieve saturation stage [12]. Meng and Wang [13], concluded that during operation, machining, storage and application the thermal aging of composite materials are affected to the climate environment such as oxygen, moisture and sunlight. Regression analysis is conducted for exploration of interaction and relationship between variables. The main benefit using regression is the capability to determine relative influence of one or more predicted variables on the dependent variables. It is also the diagnose tools to identify the abnormalities in a set of experimental results. The *p*-value less than 0.05 proved that the relationship between variables is highly significant. The R square is a coefficient to determine the percentage of the data fit to the model. Meanwhile, coefficient correlation shows how strong the relationship is positive value means positive relationship, 0 means no relationship and negative value means negative relationship among variables. In this present study the hybrid composite fibreglass with various core have been developed and subjected to various thermal aging and moisture test to analyse the effect of core on the mechanical properties of hybrid composite unsaturated composite fibreglass through experiment and regression analysis.

2 Methodology

Composite fiberglass panels consist of two different core aluminum and plywood were prepared using hand lay-up method with a thickness less than 9 mm. Matrix of unsaturated polyester with trade name Norsodyne 3338 W was used with 2% catalyst of Methyl Ethyl Ketone Peroxide (MEKP). Composite fibreglass was prepared by hand lay-up method in five-design layers using two different core materials plywood and aluminium. The laminated panels were then cured for 72 h and cut into respective sample size according ASTM for mechanical testing such as tensile (D3039), flexural (D790), impact (D6110), hardness (D2240) and moisture test (D5229). Samples were then treated at various temperature 60, 90 and 120 °C in a close oven for 2 h. Tensile and flexural tests were conducted using universal testing machine Instron 1195 with crosshead 10 mm/min and 2 mm/min respectively. Meanwhile impact test conducted by Charpy method used Charpy Izod Impact Tester 300 J (LS-22006-300 J) with a V notch. Hardness test was conducted using Brinnel method with 187.5 kg(f), ball indenter size 2.5 mm and indented at five different points to obtained average. Moisture test was conducted for 30 days and percentage weight change was recorded every 5 day. Regression method of statistical analysis was conducted for all samples in correlation to the change in temperature.

3 Results and Discussion

Figure 1 shows the flexural and impact strength of untreated (30 °C) and treated (60, 90, 150 °C) composite fiberglass with aluminum and plywood core. Meanwhile Fig. 2 shows the moisture test of composite fiberglass with aluminum and plywood core.

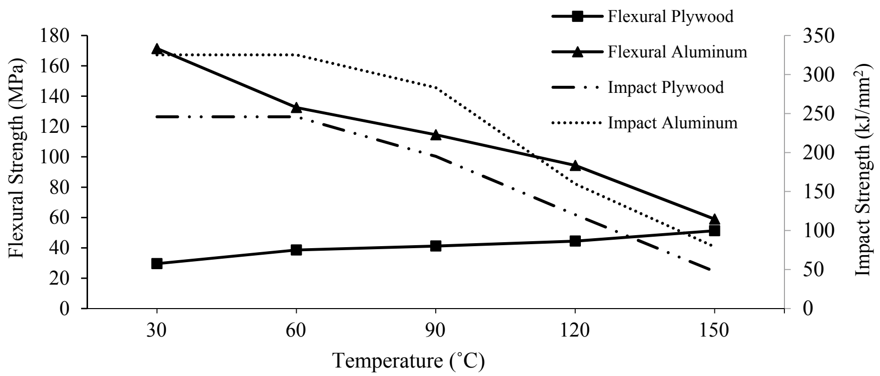

Fig. 1 Flexural and impact strength of untreated (30 °C) and treated (60 °C, 90 °C, 150 °C) composite fiberglass with aluminum and plywood core

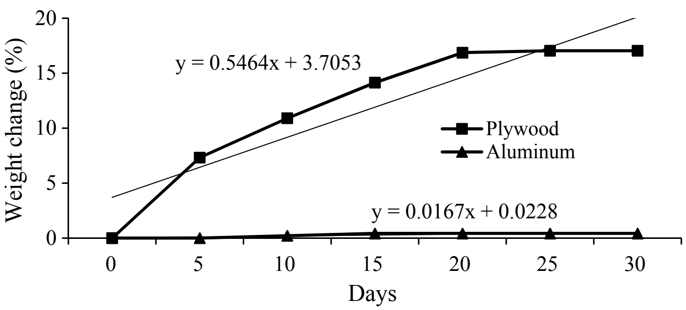

Fig. 2 Moisture test of composite fiberglass with aluminum and plywood core

Table 1 shows the summary of mechanical testing and moisture test for untreated and treated composite fibreglass with aluminum and plywood core. Tensile stress for both core aluminum increase as temperature increase up to 90 °C and it tend to decrease exceeded this temperature. Similar trend observed in four layer of fibreglass conducted by Elahi, et al. [8]. The decreasing of tensile stress is due to the decrease interaction between layer of fibreglass and aluminum core as the temperature exceeds 90 °C. Tensile strain for both core shows increasing in strain, however plywood experience higher strain value and optimum at temperature 120 °C. Meanwhile aluminum observed small increased up to 60 °C then slowly decrease in strain as temperature increased. Flexural stress observed significant increased in plywood core meanwhile aluminum shows a slight decreased as temperature increased. Flexural strain shows decreased pattern as temperature increased and in plywood strain increased optimum up to 90 °C, then decreased as temperature increased to higher temperature. The impact strength for aluminum and plywood recorded as 325.3 and 245.8 kJ/mm^2 respectively which are higher than 140 kJ/mm^2 observed in four layers of fibreglass composite without core reported earlier [8]. Impact strength observed

Table 1 Summary of mechanical testing and moisture test for untreated (30 °C) and treated (60 °C, 90 °C, 150 °C composite fibreglass with aluminum and plywood core

Properties		Aluminum				Plywood			
		p-value	CC,R	R-square (%)	Linear equation	*p*-value	CC,R	R-square (%)	Linear equation
Flexural	Stress	0.0017	−0.9907	98	y = −0.7207x + 174.9052	0.0012	0.9899	98	y = 0.1366x + 29.5179
	Strain	0.0243	0.9252	86	y = 0.000032x + 0.010067	0.9408	0.0465	0	y = 4.67E−06x + 0.0165
Tensile	Stress	0.8579	−0.1119	1	y = −0.0108x + 57.8191	0.7768	0.1762	3	y = 0.0305x + 26.3586
	Strain	0.9785	0.0169	0	y = -9.5465E-07x + 0.0306	0.1610	0.7304	53	y = 0.0002x + 0.0577
Impact	Impact strength	0.0159	−0.9437	89	y = −2.193x + 431.92	0.0097	−0.9596	92	y = −1.74x + 327.54
Hardness	BHN	0.1817	−0.7071	50	y = −0.112x + 183.94	0.7821	0.1720	3	y = 0.0793x + 168.02
Moisture	Moisture content	0.0069	0.8922	80	y = 0.0167x + 0.0228	0.0032	0.9217	85	y = 0.5464x + 3.7053

a decreased pattern as treated with increasing temperature. At temperature 150 °C all samples observed to have less than 100 kJ/mm^2 impact strength value. Hardness value for both aluminum and plywood core observed the same value 187.3 BHN, due to similar fibreglass outer layer in the untreated samples. In the treated samples, both samples observed a decreased in hardness value, however as the temperature increased to 150 °C the value increases slightly in plywood core. Aluminum core observed very small decreased in hardness value as temperature increased. Moisture absorption test observed increased in weight percentage as number of days increased in both aluminum and plywood core. Ounies, 2018 reported that the moisture concentration is higher on the surface and reduce towards the core material which explain only small increase in hybrid composite fibre especially in aluminum core. In hybrid composite fibre a dissymmetric absorption occur, produced lower diffusion due to it need to travel twice distance compared to symmetric absorption. The moisture absorption was also affected by the temperature and time of exposure that contributed to the higher moisture absorbed [12]. The regression analysis shows flexural strength, for both aluminum and plywood core produce significant p value square R value for Flexural strength observed significant values 0.0017 and 0.0012 respectively. However in the flexural strain value aluminum observed significant p value compare to plywood at increasing temperature. Meanwhile tensile stress and strain for both samples give non significant p values. Increasing temperature affected the hybrid composite fibreglass to sustain better in flexural load compare to tension load. The hybrid fibreglass also produced significant p values for both aluminum and plywood core with 0.0159 and 0.097 values respectively in the impact test. Similar observation recorded in moisture test for both core produce significant p value 0.0069 and 0.0032 for aluminum and plywood respectively. All the R-square of significant P values show high percentage more than 80% of the value fit into the linear model from regression analysis. The p-value less than 0.05 proves that the relationship between types and temperature is highly significant. The R-square near to 100% shows that the data fit to the linear relations between two variables properties and thermal aging. Coefficient correlation near to one show a strong relationship also supported similar significant finding. It can be concluded that both hybrid composite fibreglass core have a linear relation that produce significant value in flexural stress, impact and moisture test. The different in tensile and flexural stress value for aluminum and plywood core due to different corresponding microscopic failure mechanism. The embrittlement of unsaturated polyester in treated samples produce more growth of microcracks even at lower load even a single microcrack affected tensile strength of hybrid composite. In compression the biaxial/triaxial load leads to larger array of microcrack that leads to an overall toughening in the hybrid composite specimen [14]. The non-significant values in tensile stress, tensile strain, hardness testing were due to thermal aging did not produce linear relation. All samples observed a fluctuating pattern decrease value at lower temperature and reach optimum value then increases up to temperature 150 °C. Increased of hardness value was also reported earlier due to compressive triaxial during hardness which also have similar effect as in flexural test [14]. Table 1 summarize all the mechanical properties and moisture test for untreated (30 °C) and treated (60, 90, 150 °C) composite fibreglass with aluminum and plywood core.

4 Conclusion

Hybrid composite fiberglass with Aluminum core observed good mechanical properties compared to plywood in the area of flexural strength, impact and moisture resistant. Flexural strength for both Plywood and Aluminum shows significant p values, meanwhile p values for strain in aluminum observed more significant compared to plywood. Both plywood and aluminum observed significant p values in moisture test and impact strength as temperature increase. The results showed that composite fibre with Aluminum core suitable in the application related to flexural, impact and better moisture resistant compared to plywood. Thus concluded that hybrid composite fibre both core aluminum and plywood suitable for structural application at various thermal aging.

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