CHAPTER VI

CONCLUSION

6.1 CONCLUSIONS

From the experimental work performed in the present study, the results can be summarized as follows.

6.1.1 The regression analysis and the analysis of variance (ANOVA) can indicate physical aging factors that significantly affect the mechanical properties of fiber reinforced epoxy composites, and the relationship between the aging factors such as aging temperature, the presence of humidity and UV irradiation and each mechanical property. They are appropriately fitted by the multiple linear regression models and are shown in Tables 6.1 and 6.2 where x_1, x_2 and x_3 represent the coded variables of aging temperature, the amount of humidity and the presence of UV irradiation. X_1 is -1 when the composite is aged at a higher temperature while it is $+1$ when the composite is aged at a lower temperature. X_1 is -1 when the composite is aged at a higher temperature while it is $+1$ when the composite is aged at a lower temperature. X_2 is -1 when the composite is aged in dry condition while it is $+1$ when the composite is aged in wet condition. X_3 is -1 when the composite is aged without UV while it is $+1$ when the composite is aged with UV.

6.1.2 The main factors affecting the flexural strength of carbon fiber reinforced epoxy composites are humidity, temperature and interaction of thermal-UV irradiation, respectively. The significant factors influencing the flexural strength of aramid fiber reinforced epoxy composites are humidity and combined thermal-humidity effects.

Mechanical properties	Linear regression model
Flexural strength (MPa)	$y = 100.6724 - \left(\frac{7.3783}{2}\right)x_1 - \left(\frac{7.8463}{2}\right)x_2 + \left(\frac{7.2483}{2}\right)x_1x_3$
Compressive strength (MPa)	$y = 83.862 - \left(\frac{4.155}{2}\right)x_2 + \left(\frac{3.848}{2}\right)x_3 - \left(\frac{3.362}{2}\right)x_1x_2 + \left(\frac{3.872}{2}\right)x_2x_3$
Fracture toughness (MPa/m$^{1/2}$)	$y = 3.0683 + \left(\frac{0.441}{2}\right)x_1 + \left(\frac{0.7565}{2}\right)x_3 + \left(\frac{1.025}{2}\right)x_1x_3$
Fracture energy (J/m^2)	$y = 2.7291 + \left(\frac{1.2663}{2}\right)x_1 + \left(\frac{1.4108}{2}\right)x_3 + \left(\frac{2.3558}{2}\right)x_1x_3$

Table 6.1: Linear regression model from the mechanical properties of carbon fiber reinforced epoxy composites.

Mechanical properties	Linear regression model
Flexural strength (MPa)	$y = 108.7149 - \left(\frac{9.5163}{2}\right)x_2 - \left(\frac{7.3798}{2}\right)x_1x_2$
Compressive strength (MPa)	$y = 76.988 - \left(\frac{5.2533}{2}\right)x_2 - \left(\frac{2.2748}{2}\right)x_3 + \left(\frac{3.7478}{2}\right)x_2x_3$
Fracture toughness (MPa/m$^{1/2}$)	$y = 5.6093 + \left(\frac{2.96}{2}\right)x_1 - \left(\frac{0.727}{2}\right)x_2 - \left(\frac{0.337}{2}\right)x_1x_2x_3$
Fracture energy (J/m^2)	$y = 13.4226 + \left(\frac{12.7913}{2}\right)x_1$

Table 6.2: Linear regression model from the mechanical properties of aramid fiber reinforced epoxy composites.

6.1.3 Four factors namely humidity, combined humidity-UV irradiation, UV irradiation, and combined thermal-humidity influence the compressive strength of carbon fiber reinforced epoxy composites, respectively. The main factors affecting the compressive strength of aramid fiber reinforced epoxy composites are humidity, combined humidity-UV irradiation, and UV irradiation, respectively.

6.1.4 The significant effects affecting the fracture toughness and the fracture energy of carbon fiber reinforced epoxy composites are temperature, UV irradiation and combined thermal-UV irradiation, respectively. For aramid fiber reinforced epoxy composites, the main factors influencing the fracture toughness are temperature, humidity and combined thermal-humidity-UV irradiation effects, respectively. Only temperature is the significant effect of the fracture energy of aramid fiber reinforced epoxy composites.

6.1.5 The glass transition temperature increases slightly with the aging temperature. This is due to an increase in the crosslink density upon thermal aging.

6.1.6 Humidity affects the mechanical properties of fiber reinforced composite because humidity is trapped between the epoxy matrix and fiber, causing poor adhesion at the interface of the composites. Specifically, aramid fiber can bring about the hydrogen bond with water in the fiber structure, making it difficult molecular movement in the fiber reinforced composite. Another reason is that the hydrogen bonding causes the separation of the chains and increases their general mobility. It is the effect of plasticization that results in the reduction in the T_g.

6.1.7 UV results in weakening and embrittlement of composites because UV brings about the thermal oxidation of epoxy matrix as was verified by FTIR.

6.1.8 The temperature dependence of the shift factor can be represented by WLF equation in which the C_1 and C_2 parameters are modified. They were determined for the corresponding glass transition temperature and properly fitted in Table 6.3 shows the equations for the modified parameters for each composite. Tg is the glass transition temperature of fiber reinforced epoxy composite.

Material	Modified parameter
Carbon fiber reinforced epoxy composites	$C_1'' = \dfrac{83.6555}{467.3854 - T_g'}$ $\quad C_2'' = 467.3854 - T_g'$
Aramid fiber reinforced epoxy composites	$C_1'' = \dfrac{53.029}{443.1501 - T_g'}$ $\quad C_2'' = 443.1501 - T_g'$

Table 6.3: Modified parameters for the WLF equation of carbon fiber and aramid fiber reinforced epoxy composites.

6.2 RECOMMENDATIONS FOR FURTHER STUDY

6.2.1 Other aggressive environments such as the exposure of fiber reinforced epoxy composites to various chemical reagents are an area that still opens for investigation.

6.2.2 Physical aging effects on the mechanical properties of fiber reinforced epoxy composites for coating of concrete can be studied.

6.2.3 Actual outdoor exposure with prolonged aging time can be conducted in order to compare with the accelerated aging.