2011 IEEE Nanotechnology Materials and Devices Conference
October 18-21, 2011, Jeju, Korea.

Regression model of oxidation behavior of 6061 Al/SiC composite with and without protective coatings

Priyamvada.B[1*] Rajasekaran.S[2] N. K. Udayashankar[3] and Jagannath Nayak[4]

Abstract - **This paper analyses the variation of weight gain, Δm, of 6061 Al/SiC composite due to oxidation with time, t, using regression model. Using curve fitting technique, the mathematical equations for the oxidation behavior of the composite are formulated. The generated data according to the mathematical equations are analyzed and compared with the experimental data. More specifically, regression analysis helps in understanding how the typical value of the mass gain (dependent variable) changes when the time of oxidation (independent variable) is varied, while the other independent variable (Temperature) held fixed. Since the oxidation resistance of the 6061Al/SiC composite decreases due to the presence of alloying elements precipitates in the matrix, the effect of aging treatment and protective coatings like Aluminium and AlCrN on the oxidation behavior of the composite is studied. It is observed that the coatings increase the oxidation resistance of the composite. The regression analysis carried out shows a threefold linear variation of weight gain (Dependent variable) with respect to time and temperature of oxidation (Independent variables).**

Key Words: 6061Al/SiC Composite, Regression model, AlCrN and Oxidation behavior.

I. INTRODUCTION

In statistics, regression analysis includes any techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables.

Priyamvada. B is with the Department of Metallurgical and Materials Engineering, National Institute of Technology Karnataka, Surathkal, Srinivasnagar, Dakshina Kannada District, Mangalore -575 025, India. (e-mail: priyamvada.quantummultiverse@gmail.com).
Rajasekaran. S is with the Department of Metallurgical and Materials Engineering, National Institute of Technology Karnataka, Surathkal, Srinivasnagar, Dakshina Kannada District, Mangalore -575 025, India.
N. K. Udayashankar is with the Department of Physics, National Institute of Technology Karnataka, Surathkal, Srinivasnagar, Dakshina Kannada District, Mangalore -575 025, India.
Jagannath Nayak is with the Department of Metallurgical and Materials Engineering, National Institute of Technology Karnataka, Surathkal, Srinivasnagar, Dakshina Kannada District, Mangalore -575 025, India.

More specifically, regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed. Most commonly, regression analysis estimates the conditional expectation of the dependent variable given the independent variables that is, the average value of the dependent variable when the independent variables are held fixed. A large body of techniques for carrying out regression analysis has been developed. Familiar methods such as linear regression and ordinary least squares regression are parametric, in that the regression function is defined in terms of a finite number of unknown parameters that are estimated from the data [1]. The performance of regression analysis methods in practice depends on the form of the data-generating process, and how it relates to the regression approach being used. Since the true form of the data-generating process is in general not known, regression analysis often depends to some extent on making assumptions about this process. These assumptions are sometimes (but not always) testable if a large amount of data is available. Regression models for prediction are often useful even when the assumptions are moderately violated, although they may not perform optimally [1], [2].

II. EXPERIMENTAL WORK

In this work, the oxidation data of 6061Al/SiC composite with and without protective coatings is analyzed using linear regression model. In this analysis, temperature is taken as independent variable (fixed variable); weight gain and time of oxidation are taken as dependent variables. From the experimental data, it is observed that the oxidation profile shows a threefold linear behavior. The oxidation profiles corresponding to 1 to 10 minutes, 10 to 90 minutes and 90 to 1000 minutes are analyzed independently. By means of curve fitting method the linear mathematical equations with constants, corresponding to oxidation profiles of the composite are obtained. The following equation is used in regression analysis,

$$\Delta m = k_1 t + c \qquad (Linear\ equation)$$

Where Δm – Mass gain (g/cm^2)

k_1 and c – constants

t – Time of oxidation (min)

The constants of the linear equations and correlation coefficients obtained in curve fitting method are tabulated in table 1 to 5. Figs 1 to 3 represent the curve fitting analysis of the oxidation profiles of the composite with and without protective coatings at 500 K. The corresponding model generated oxidation profiles are shown in Fig 4 to 6.

III. RESULTS AND DISCUSSIONS

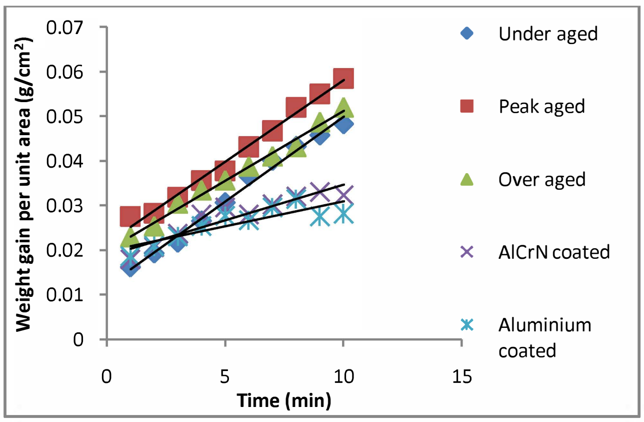

Fig.1 Curve fitting plot for the oxidation profile at 500 K for the time period from 1 to 10 minutes.

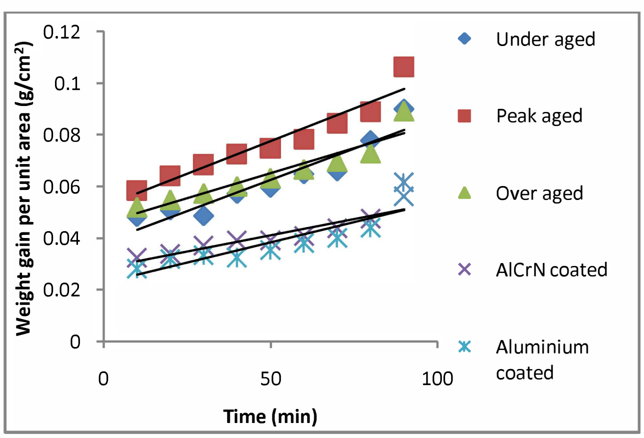

Fig.2 Curve fitting plot for the oxidation profile at 500 K for the time period from 10 to 90 minutes.

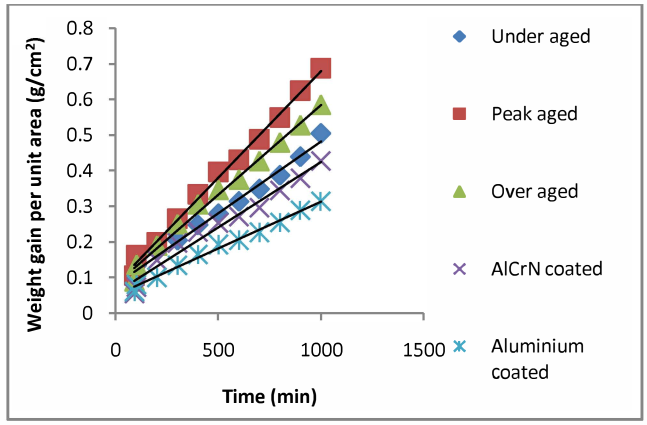

Fig.3 Curve fitting plot for the oxidation profile at 500 K for the time period from 90 to 1000 minutes.

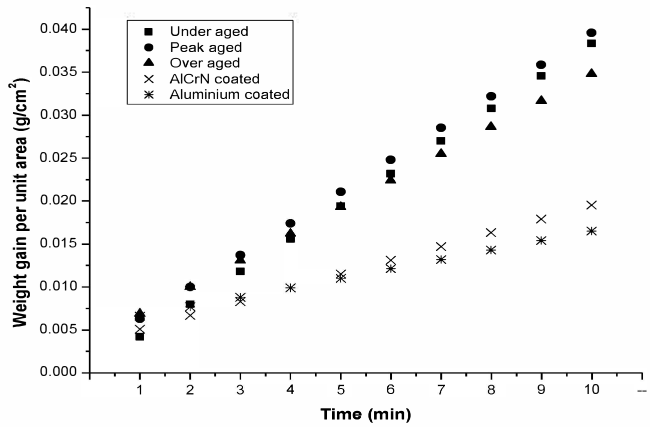

Fig.4 Model generated oxidation profile at 500 K for the time period from 1 to 10 minutes.

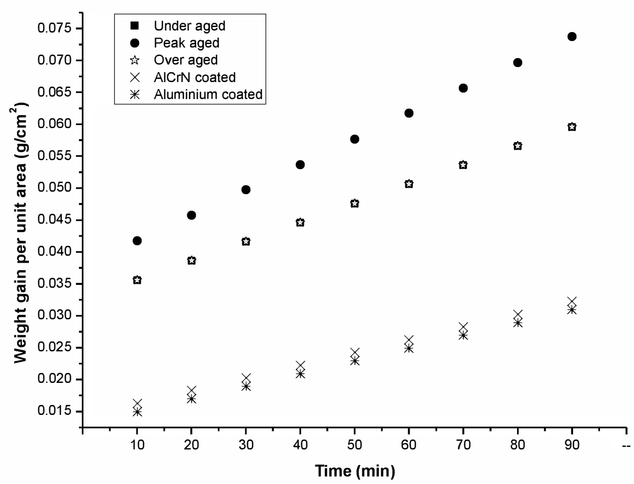

Fig.5 Model generated oxidation profile at 500 K for the time period from 10 to 90 minutes.

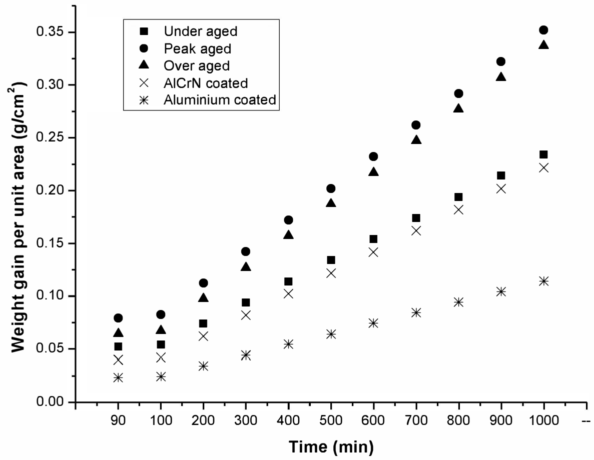

Fig.6 Model generated oxidation profile at 500 K for the time period from 90 to 1000 minutes.

Table 1 Constants obtained in curve fitting method for under aged composite

Time (min)	Temperature (K)	Constants		
		Under aged		
		k_1	c	R^2
1 to 10	500	0.0038	0.0004	0.9895
	600	0.0038	0.0024	0.9892
	700	0.0038	0.0066	0.9897
	800	0.0038	0.0119	0.9895
10 to 90	500	0.0003	0.0326	0.942
	600	0.0005	0.0296	0.9499
	700	0.0005	0.033	0.8899
	800	0.0005	0.0383	0.8891
90 to 1000	500	0.0002	0.0338	0.9984
	600	0.0002	0.0729	0.9906
	700	0.0004	0.0594	0.9829
	800	0.0004	0.0787	0.9875

Table 2 Constants obtained in curve fitting method for peak aged composite

Time (min)	Temperature (K)	Constants		
		Peak aged		
		k_1	c	R^2
1 to 10	500	0.0037	0.0026	0.9884
	600	0.0037	0.0088	0.9876
	700	0.0037	0.0146	0.9884
	800	0.0037	0.0215	0.9882
10 to 90	500	0.0004	0.0377	0.9903
	600	0.0006	0.0401	0.9891
	700	0.0004	0.0474	0.9856
	800	0.0005	0.0521	0.9234
90 to 1000	500	0.0003	0.052	0.9939
	600	0.0004	0.0894	0.9867
	700	0.0004	0.1023	0.9769
	800	0.0006	0.082	0.9938

Table 3 Constants obtained in curve fitting method for over aged composite

Time (min)	Temperature (K)	Constants		
		Over aged		
		k_1	c	R^2
1 to 10	500	0.0031	0.0038	0.9901
	600	0.0031	0.0088	0.9909
	700	0.0031	0.0135	0.9906
	800	0.0031	0.0199	0.9904
10 to 90	500	0.0003	0.0326	0.9981
	600	0.0005	0.0338	0.9784
	700	0.0003	0.0423	0.9981
	800	0.0004	0.0456	0.8874
90 to 1000	500	0.0003	0.0368	0.9948
	600	0.0003	0.072	0.9881
	700	0.0004	0.0843	0.9767
	800	0.0005	0.0813	0.99

Table 4 Constants obtained in curve fitting method for AlCrN coated composite

Time (min)	Temperature (K)	Constants		
		AlCrN Coated		
		k_1	c	R^2
1 to 10	500	0.0016	0.0035	0.8779
	600	0.0016	0.0074	0.8589
	700	0.0018	0.0113	0.9041
	800	0.0016	0.0187	0.8779
10 to 90	500	0.0002	0.0149	0.9722
	600	0.0002	0.0188	0.9711
	700	0.0002	0.0234	0.9720
	800	0.0003	0.0284	0.8913
90 to 1000	500	0.0002	0.0217	0.9952
	600	0.0002	0.053	0.9569
	700	0.0003	0.0545	0.9689
	800	0.0004	0.0572	0.9707

Table 5 Constants obtained in curve fitting method for AlCrN coated composite

Time (min)	Temperature (K)	Constants		
		Aluminum coated		
		k_1	c	R^2
1 to 10	500	0.0011	0.0055	0.7399
	600	0.0011	0.0089	0.7584
	700	0.0011	0.0134	0.7391
	800	0.0011	0.0197	0.7394
10 to 90	500	0.0002	0.0129	0.9271
	600	0.0002	0.0164	0.9106
	700	0.0002	0.0208	0.9271
	800	0.0003	0.0226	0.7549
90 to 1000	500	0.0001	0.014	0.993
	600	0.0001	0.0376	0.9686
	700	0.0002	0.0456	0.9672
	800	0.0003	0.0513	0.9924

The curve fitting analysis (Fig 1 to 3) clearly indicates that the oxidation profile exhibits three stage linear behavior. The values of correlation coefficient (R^2) obtained for the regression analysis exist in acceptable range. The fresh surface of polished composite specimen simulates the machined component made of this material after the casting technique followed by aging treatment [3]. When the polished specimens exposed to air at high temperatures, the oxidation rate is severe at initial stages (From 1 to 10 minutes of oxidation). This is evident by analyzing the constant values (k_1 and c) of regression data. The formation of oxide film during the initial period decreases the further oxidation process and hence the oxidation rate. Therefore, from 10 to 90 minutes, a linear curve of smaller slope is observed. The thermal degradation of the oxide film may expose the sub layers of the matrix to air as time of oxidation increases [3]. Hence above 90 minutes, an increase in oxidation rate is observed. The oxidation profiles of aluminium and AlCrN coated composite show similar trend as that of the aged composite but with lower oxidation rate. This is in agreement with the correlation constants (k_1 and c) obtained for the composite with protective coatings.

IV. CONCLUSION

The regression analysis proves that the oxidation profiles of the 6061 Al/SiC composite with and without protective coatings show a threefold linear behavior for oxidation time from 1 to 1000 minutes.

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