BASED ON THE CHARACTERISTIC PARAMETERS ESTIMATE MANUFACTURING COST FOR COMPOSITE STRUCTURES

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Abstract

With the wide application of composite materials, in order to make composite structures competitive in the market, cost estimation tools must be used to enable design engineers and manufacturing engineers to accurately estimate the cost of structures to reduce the cost of composite structures. In this paper, a method for estimating the cost of composite structures based on characteristic parameters is proposed. The possible influence parameters of the cost of the structures are obtained through investigation, and the cost data and characteristic parameters are collected. The multi-class variable conversion technology is used to obtain the cost model. From the results, we can know that the obtained fitting accuracy can meet the engineering requirements. We also give the relationship between all cost items and weight, these regression models can quickly estimate the cost of composite structures by simply counting the weight parameter data, and can be used in engineering design.

Keywords: Composite Material; Cost Estimation; Characteristic Parameters

1. Introduction

Composite materials can be providing superior strength to weight ratios when compared to metals, the use of composite structures has been gradually increasing in the aerospace industry due to their excellent performance in terms of high strength with low weight and potentially lower life-cycle costs [1]. However, manufacturing composite components are known to consist of labor-intensive high-cost processes, and material costs are comparatively higher for high-performance carbon fiber. Therefore, cost control becomes the primary objective during a project start phase and cost estimation and cost modeling must be done to know future manufacturing costs and achieve Multi-objective optimization design before or during the product design phase [2-8]. The existing cost estimation methods can be classified into the three primary methods: analogous, parametric, and bottom-up cost estimation. The analogous costing methodology is characterized by adjusting the cost of a similar product relative to differences between it and the target product [9]. The prime principle of parametric cost estimation is the building of so-called “Cost Estimation Relationships” (CERs). These CERs are more or less simple mathematic relations between the costs of a product or system and some of its parameters known as “Cost Drivers” [10]. In bottom-up estimations, all work steps, with their costs for material, work, infrastructure, etc., are added up to produce the products final costs. For this kind of estimation or calculation deep understanding of the process, the process interactions and the part design details have to be available [11,12]. The key advantages and limitations of the three basic methods are summarized and are presented in Table 1 [13, 14].

Table 1 –Summary of advantages and disadvantages of the three main cost estimation methods.

Method	Advantages	Disadvantages
Analogous	Cause and effect understood; Quick and easily applied; Based on actual historical data; Accurate for minor deviations from analog.	Appropriate baseline must exist; Identifying the appropriate analog can be difficult; Substantial, detailed data are required; Requires expert knowledge/judgement for adjustment factors.

Parametric	Easiest to implement; Developed CERs are excellent tools for “what-if” analysis; Non-technical experts can apply method, no reliance on opinion; “Statistical” uncertainty of the forecast is generated; Allows scope for quantifying risk.	Can be difficult to develop; Factors might be associative but not causative (i.e. lack of direct cause-and-effect relationships; Relationship might not be easily understandable; Selection and adjustment of raw data and development of equations, statistical findings conclusions must all be documented for validation; Extrapolation of existing data to forecast the future, which include radical technological changes, might not be properly forecast; Loses predictive credibility outside its relevant data range.
Bottom-up	Cause and effect understood; Intuitive and defensible; Very detailed estimate; Provides insight into major cost contributors; Miscalculation of an individual element does not compromise entire estimation.	Difficult to develop and implement Substantial, detailed expert data are required; Requires expert knowledge; Significant effort (time and money) required to create an estimation; Does not provide good insight into cost drivers; Estimate must be “built-up” for each alternative scenario, not responsive for “what-if” analysis.

In this paper, we give a parametric cost estimation method to calculate the manufacturing cost of composite structures based on the characteristic parameters, the approach outlined here in three steps: (1) data collection; (2) development of cost estimation relationship; (3) result analysis.

2. Formulating the Manufacturing Cost Estimation Model

2.1 Data Sources

We collected 49 data samples from different composite structures of aerospace industry, including 6 output variables and 12 input variables, the detailed parameters are shown in Table 2.

Table 2 –Detailed parameters of manufacturing cost estimation.

No.	Parameter	property	Symbolic representation	unit
1	Labor hours	output	Y1	h
2	Main material cost	output	Y2	yuan
3	Auxiliary material cost	output	Y3	yuan
4	Testing cost	output	Y4	yuan
5	Molding tooling cost	output	Y5	yuan
6	Manufacturing cost	output	Y6	yuan
7	Weight	input	X1	kg
8	Structure type	input	X2	/
9	Molding	input	X3	/

	process			
10	Blanking process	input	X4	/
11	Paving process	input	X5	/
12	Comprehensive utilization rate of materials	input	X6	%
13	Curing times	input	X7	/
14	Whether to combine tooling	input	X8	/
15	Tooling complexity	input	X9	/
16	Main reinforcement type	input	X10	/
17	Fiber surface density/ Weight after curing	input	X11	kg
18	Unit price of prepreg	input	X12	Yuan/kg

The variables of 'Molding process', 'Blanking process', 'Paving process' and 'Whether to combine tooling' are dichotomous variables. The variables of 'Structure type', 'Tooling complexity and 'Main' reinforcement type' are multi-categorical variables. The others are continuous variables.

If categorical variables will be used in a regression analysis, they need to be coded by one or more dummy variables (also called tag variables). For dichotomous variables, each such dummy variable will only take the value 0 or 1, the encoding results of four dichotomous variables are shown in Table 3- Table 6. For a multi-categorical variable with *n* possible values, the coding method is to convert the variable into *n*-1 dichotomous variables. Here we give the encoding results of three multi-categorical variables, as shown in Table 7- Table 9.

Table 3 –The encoding result of a dichotomous variable (Molding process).

X3（Molding process）	**value**
Autoclave process	0
RTM/VARTM/VARI	1

Table 4 –The encoding result of a dichotomous variable (Blanking process).

X4（Blanking process）	**value**
manual	0
automatic	1

Table 5 –The encoding result of a dichotomous variable (Paving process).

X5（Paving process）	**value**
Laser projection assisted manual	0
manual	1

Table 6 –The encoding result of a dichotomous variable (Whether to combine tooling).

X8（Whether to combine tooling）	**value**
Yes	0
No	1

Table 7 –The encoding result of a multi-categorical variable (Structure type).

X2（Structure type）	**value**	**X2_1**	**X2_2**
Laminate	1	1	0
Honeycomb sandwich structure	2	0	1
Reinforced structure	3	0	0

Table 8 –The encoding result of a multi-categorical variable(Tooling complexity).

X9（Tooling complexity）	**value**	**X9_1**	**X9_2**
Simple	1	1	0
Medium	2	0	1
Complex	3	0	0

Table 9 –The encoding result of a multi-categorical variable (Main reinforcement type).

X10（Main reinforcement type）	**value**	**X10_1**	**X10_2**
Unidirectional	1	1	0
Fabric	2	0	1
Unidirectional and Fabric	3	0	0

2.2 Model Formulation

The linear regression method is used to construct the cost estimation model of composite structures, as shown in the following formula:

$$y = a_0 + \sum_{i=1}^{n} a_i x_i \tag{1}$$

Where y is the cost item of the composite structures, x_i is the characteristic parameter of the composite structures, a_i is the regression coefficients, and n is the number of the characteristic parameters of the composite structures after conversion. Based on the collected data and converted data, the results of the regression are shown in Table 10.

Table 10 –the results of the regression for different cost items.

Parameter	Coefficient	Y1	Y2	Y3	Y4	Y5	Y6
Constant term	a_0	10641.7	744777.2	286900.1	49900.8	395556.0	245706.0
X1	a_1	56.2	10588.5	1344.8	642.2	240.5	25699.3
X2_1	a_2	-4099.8	-3942.9	-139104.6	-61563.5	119983.4	-654342.2
X2_2	a_3	-42.0	-64259.5	-14979.8	724.1	-6008.3	281022.7
X3	a_4	-	-	-	-	-	-
X4	a_5	-	-	-	-	-	-
X5	a_6	1549.3	-361269.3	-53998.7	-31449.5	-36551.5	1826356.4
X6	a_7	-12890.9	-1855118.5	-327640.0	-168997.5	-73883.8	4982611.7
X7	a_8	82.6	5776.0	-15229.8	571.8	-3038.9	240413.0
X8	a_9	-	-	-	-	-	-
X9_1	a_{10}	-4864.4	-186526.7	-91755.1	25800.3	-356834.2	-544853.3
X9_2	a_{11}	-3167.3	-126639.0	-91213.7	37909.2	-338269.8	107401.8
X10_1	a_{12}	2990.3	469005.5	16057.7	36486.4	19134.7	-1238507.9
X10_2	a_{13}	3727.7	436836.5	54143.1	34862.3	12377.6	16164.9
X11	a_{14}	-6994.8	581584.8	-266736.8	-19227.4	102981.6	-12290000.0
X12	a_{15}	-0.5	-128.4	37.9	-11.1	-24.3	633.6
R^2		0.998	0.993	0.993	0.987	0.999	0.984

2.3 Results

Through the above regression results, we can see that the regression R-squared is guaranteed to be above 0.9, weight of composite structure and all cost items are positively correlated, all cost items variables are independent of the three variables of molding process, blanking process and whether to combine tooling.

In order to quickly estimate the manufacturing cost of composite structures and avoid the problem of collecting data, we have given that weight is only considered as a factor affecting cost, and a linear regression model has been established. The regression results are as follows in Figure 1-Figure 6.

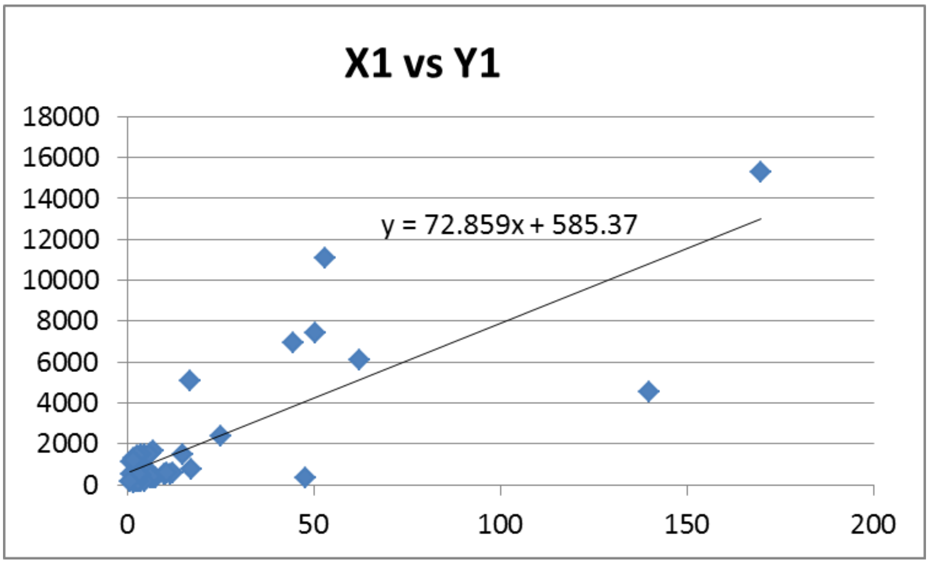

Figure 1 – The relationship between labor hours and weight.

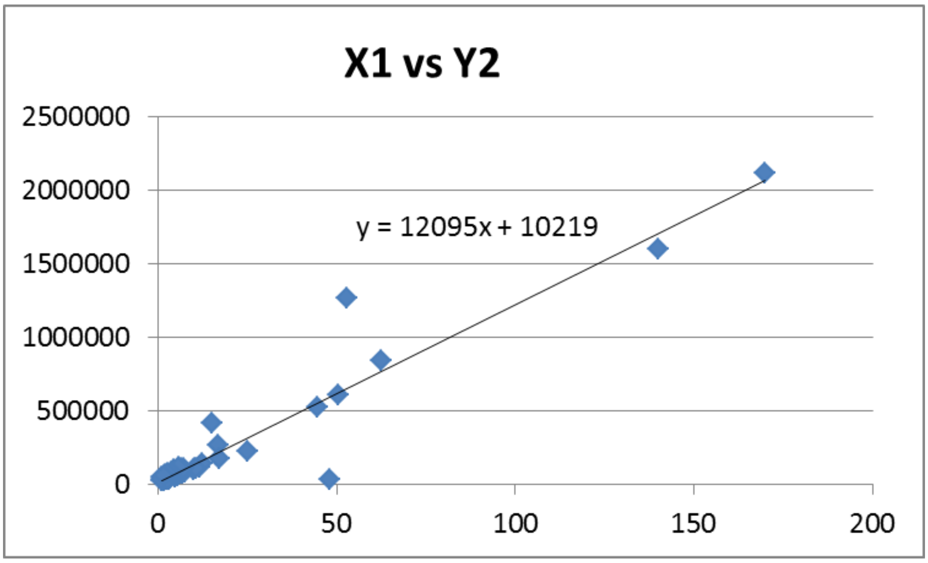

Figure 2 – The relationship between main material cost and weight.

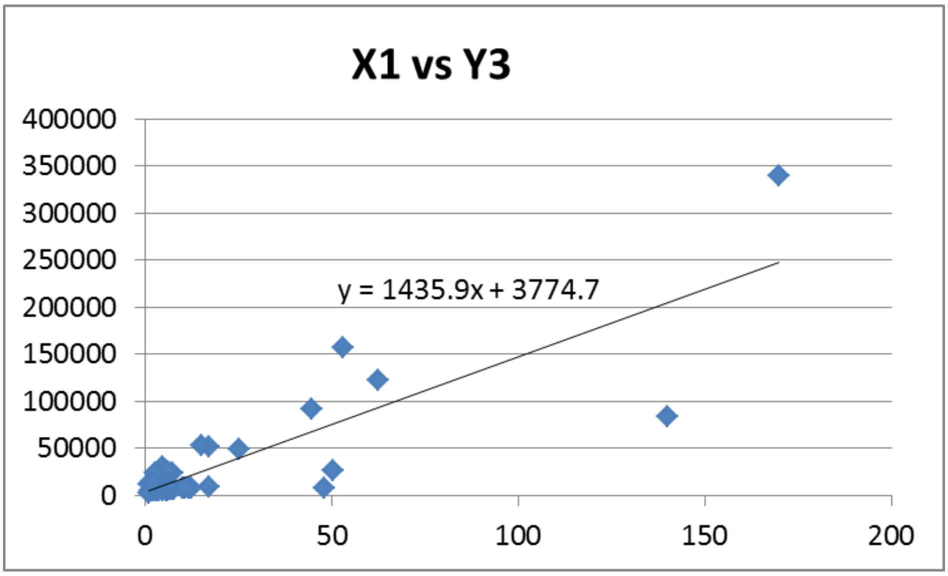

Figure 3 – The relationship between auxiliary material cost and weight.

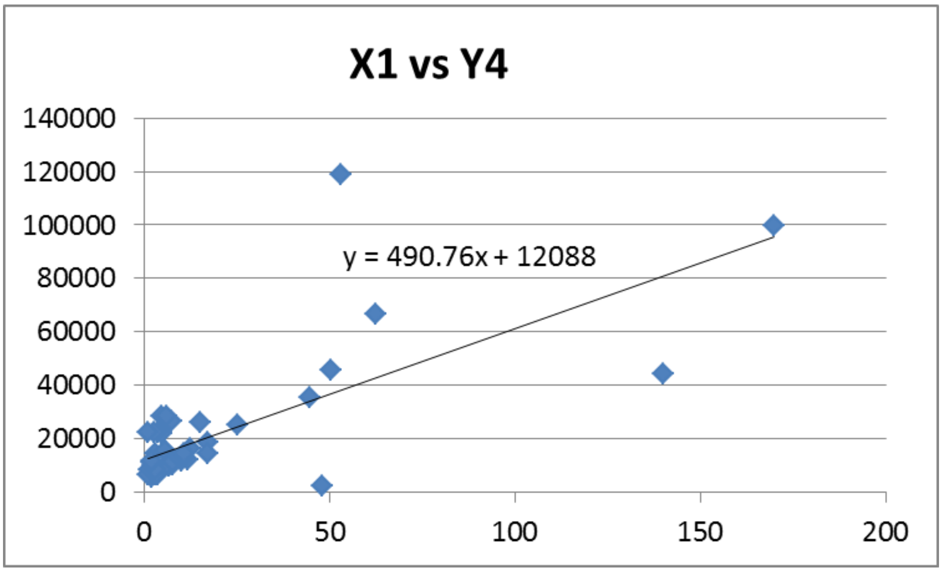

Figure 4 – The relationship between testing cost and weight.

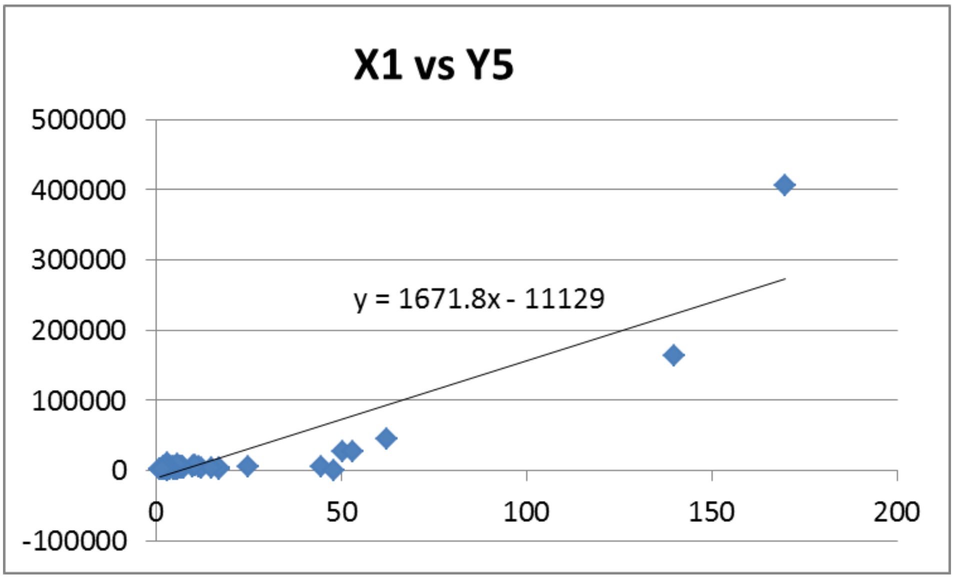

Figure 5 – The relationship between molding tooling cost and weight.

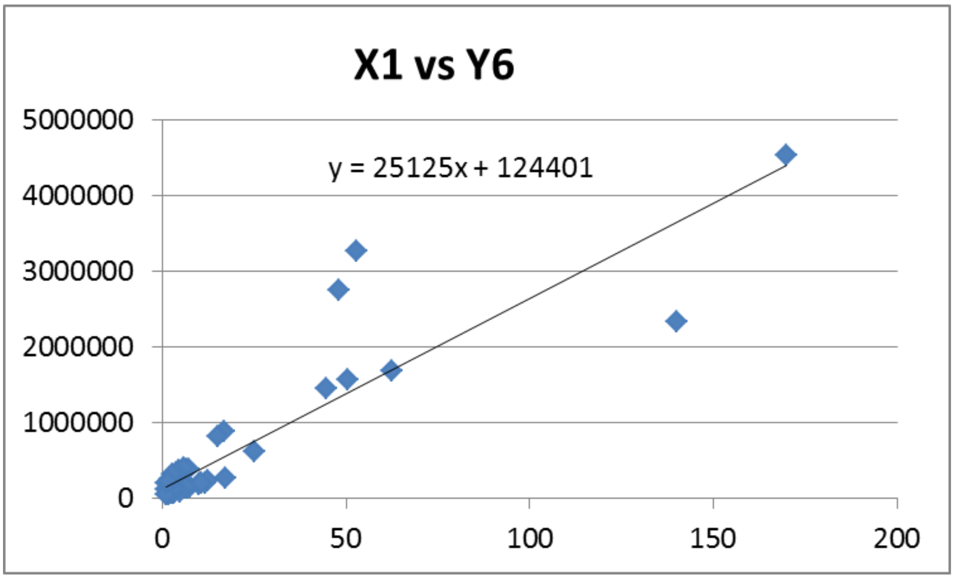

Figure 6 – The relationship between manufacturing cost and weight.

3. Conclusion

By communicating with experts in composite material structure manufacturing enterprise, we obtain possible factors affecting the cost of composite structures and collect relevant parameter data. By adopting a multi-categorical variable conversion method, it is possible to regress mixed variables. From the regression results, we can see that: 1) For the output cost variables, the use of linear regression can basically make the regression results meet the accuracy requirements, and the regression R-squared is guaranteed to be above 0.9; 2) The output cost variables are independent of the three variables of molding process, blanking process and whether to combine tooling; 3) The cost evaluation model of composite structures based on the weight parameter established by the research can realize the rapid estimation of the manufacturing cost of composite structures.

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5. Copyright Statement

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