

Research of CAPP Based RTM Process Design Method for Composite Materials

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Abstract Aimed at the fast and low cost forming process of composite, this paper uses CAPP(Computer Aided Process Planning) technology for raising the level of computer application from product design, technological design to product manufacturing all-sidedly. It is built with taking CAPP as the core information-processing mode, realize the real-time linked relation of CAPP to product design and manufacturing, finish closed-loop control of product-making process, and implement the automation of composite manufacture. This automatic system is set up with computer control for center, and multiple operation units for the complement, which implement the automation of composite manufacture. To the processing method of composite, on the basis of CAPP, this text has put forward a kind of new processing design method, namely progressive process development based on feature prototype. This method changes traditional 'linear batch processing' method. Analyze the properties of products' shape at first, set up the prototype of RTM technological process of this product to the processing technique feature of the main shape, and then with the gradual increase of the product information, adjust and supplement the prototypes of technological process constantly, finally finish the technological design of the whole products gradually. This design accords with the thought process of technological design that processing designers carry on. The prototype of products' technological process could reflect processing design better. On the other hand, this paper summarizes the reasoning method of group technology for composite, namely fuzzy classified reasoning algorithm. This paper summarizes composite fuzzy classified basic conception, essentiality and its practicability and validity in composite products coding, which offers the important basis for the composite CAPP expert system.

Keywords CAPP, composite, automation, feature technique, coding technique

1 Introduction

The advanced composite is a developing focus of the new material in the 21st century. It is the fine structural material and the ideal function material as well, so there are great practical value and wide development prospect in lots of fields. At present, research of composite is concentrated on the study of its solidification on mechanism and forming method mainly ^[1]. The forming process of the composite is being developed constantly too. RTM technology developed rapidly in recent years ^[2-4], namely the technology of resin transfer molding, is one of the main developing directions of manufacturing technology in the fields of aerospace at present. Aerospace composite components have the production feature of little batch and infinite varieties. To adapt to this feature, RTM forming process have made fast progress with the long-term development of materials industries and the constant advancement of processing technique, and entered and developed to a climax in Europe, the United States and Japan at the end of the eighties. At this period of time, the equipment, resin and mould technology of RTM forming process was improved too. In U.S.A., RTM increases with the rate of 20% to 25% every year. According to the estimation by experts^[5-6], RTM will become one of the leading forming processes in the fields of glass fibre reinforced plastic / composite in the 21st century, which will make the cost of the advanced composite reduce by 25% - 40%.

With the development of production technology and the request that produce much varieties in batches, especially CAD/CAM system developing in the integrated, intelligent direction, traditional processing method has been far from meeting the manufacturing demands, at this historic moment, computer aided process planning (CAPP) arise ^[7-9]. With CAPP, traditional technological design can overcome its shortcoming, shorten its cycle greatly, guarantee its quality, improve its standardization for enterprise, and is favorable to its optimization. At present, CAPP has been introduced among the composite production successfully. It links up the design and manufacturing of composite product organically, and makes knowledge and information during design process apply to the manufacturing process possibly. CAPP has the essential function on the automation of composite, we can say, it will have no automation of composite if having no CAPP.

CAPP has the following merits in forming technology ^[10]:

- (1) Can liberate the technological designer from a large amount of strenuous and repeated manual labors, enable them engaged in creative work such as the development of new product, improvement of process equipment, and study on new

- process;
- (2) Can shorten the design cycle greatly, guarantee the designing quality, improve the competitive power on the market of the products;
 - (3) Inherit the experience of skilled technological designer, improve design competence;
 - (4) Can improve enterprise standardization of technological design, is favorable to the optimization of design;
 - (5) Set the essential technological foundation for realizing design-manufacturing system integration

With the change of international situation, even products with technological advantage in the national defense industry, need keeping the competitiveness through lowering costs. In order to reduce the cost, it is an international major trend that improves automatic level of the process done by hand all-sidedly. The main advantage of composite automatic manufacturing lies in: realize the automatic procedure from design to production, improve the quality of products and homogeneity of products, decrease wasting raw materials, reduce the cost and shorten the cycle of developing and production. Automation of composite is the whole technological process from the computer-aided product planning of composite, computer aided process planning to computer aided manufacturing. CAPP joins the product design and manufacturing. Automation production runs through product design, process planning and the whole procedure in production.

To RTM, the composite fast low cost forming process, we should improve the computer application level from product design, process planning to manufacturing. Utilizing advanced sensing technology of optical fibre, we can obtain information of solidification within composite, for instance, solidification temperature, strain etc. According to the process information obtained, as the suction parameters of forming procedure, we set up the system taking CAPP as the core information processing mode, realize the real-time linked relation of CAPP to product design and manufacturing, finish closed-loop control of product-making process, and implement the automation of composite manufacture.

Feature technology, parameter designing technique and artificial intelligence is the basic technology in the research of CAPP system. Using those technologies for the process design is determined by their own superiority. Feature technology was put forward by an academic thesis "feature expression of CAD product", which was published by department of mechanical engineering, Massachusetts Institute of Technology of American in June 1978. After more than ten years' progress^[11-12], feature technology has already obtained greater development. Especially ISO issued PDES/STEP standard draft at the end of 1988, after classifying the shape, tolerance and material feature as the key element of the product information model, feature modeling obtained legal status even more. But making a general survey of domestic and international current situation, we find if having different understanding in the meaning, function, research focal point and study direction of feature, we will get different technology routes. This respect of academic thought activates very much such as professor A.Y.C.Nee of Singaporean national university, Usher, John M. and Fernandes of the Mississippi university of U.S.A., kiran J. and W. Eversheimdeng. In china, works in this respect have already begun by many people such as Zhao Ru Jia and Jiang Ping Yu of Xi'an Communications University, Duan Wei Gen of mechanical department of Shanghai jiao tong university, Xiang Wen of Huazhong university of science and technology, Wang Xian Kui of Tsinghua university^[13-15]. It regards regard feature as the base unit in the course of design, forms the file of cutter spacing based on feature while processing; On the other hand, the feature has geometry topological structure more simple to the products. Using the proper expression method, we can provide one information model that computer can understand, thus form a production technology course of automation. So launching this research has greater open-up meaning.

Analyzing the main feature of classified code system both at home and abroad, combined with feature design, we adopt some structure and develop a kind of categorized code system of flexibility based on feature; study process decision-making technique based on the feature modeling, develop a kind of process reasoning tool suitable for process design, through using this reasoning tool realize the semi-automatic production of RTM.

2 Technological design method for Composite CAPP system

Primary elected product scheme is the typical craft of the product clan, but to concrete

product, this product scheme need some essential modification and adjustment according to concrete feature. To the feature key element that original scheme does not involve, usually, we need taking the shape feature of this key element, feature of specific strength and feature of specific modulus as the criterion of reasoning. Through reasoning machine of intelligence system, introduce the processing method of this product's feature and processing parameters of key element to form the special-purpose product scheme that suits the concrete product.

It is a complicated course of establishing the composite processing method, not merely affected by technological requirement, but the equipment, the experience of personnel, grasped knowledge of process and people's habit as well, so to the same product, different person may make different technological route. Thus using pure reasoning way of mathematics and knowledge representation based on IF-THEN fixed numerical value for threshold value, seems extremely single and not reliable. It is a better way of solving this kind of problem that the reasoning of knowledge description based on fuzziness and hierarchy association function of nerve network. As to one feature, its processing technology is determined by dimension, strength and modulus etc.

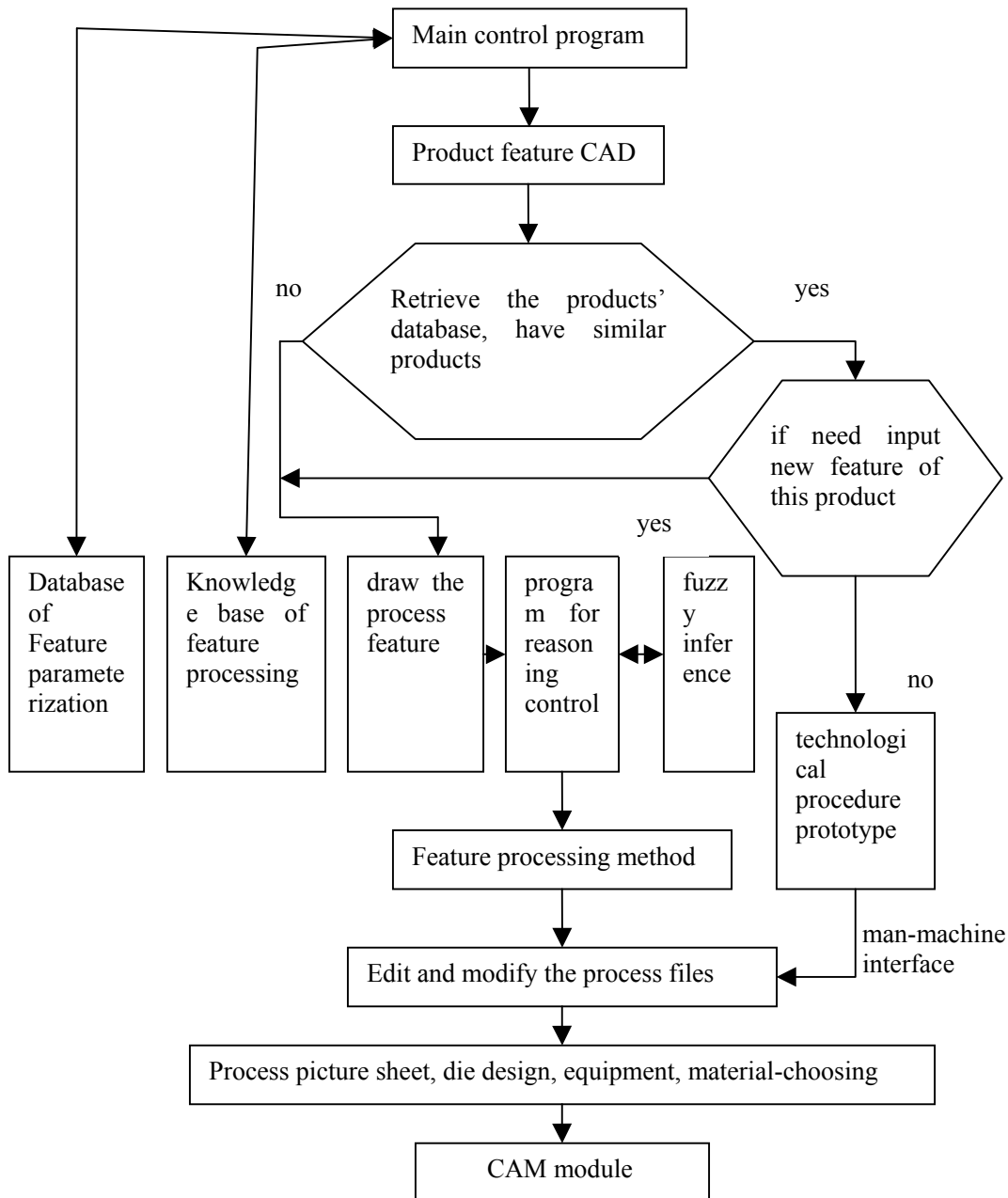


Figure 1 schematic diagram of processing design based on feature

This paper has put forward a kind of new processing design method, namely progressive process development based on feature prototype. This method changes traditional ‘linear batch processing’ method. Analyze the properties of products’ shape at first, set up the prototype of RTM technological process of this product to the processing technique feature of the main shape, and then with the gradual increase of the product information, adjust and supplement the prototypes of technological process constantly, finally finish the technological design of the whole products gradually. This design accords with the thought process of technological design that processing designers carry on. The prototypes of products’ technological process reflect processing design better. Figure 1 is a schematic block diagram of this method. RTM processing prototype reflects the processing technology of main feature of products. It is the abstract expression of processing technology universally. It determines the processing of this product basically. Generally, there three kinds of ways to establish the prototype of the products’ processing, as following shows:

- 1) Abstract the having products’ processing
- 2) Automatic reasoning on the basis of the design knowledge
- 3) Man-machine interaction

After setting up processing prototype, we should consider increasing new feature impact on this product’s processing. New feature include main feature or some supplementary features that are added when revising the design repeatedly. To these influence factors, we can make proper adjustment and supplement to this prototype. And this job can be finished by man-machine interaction or automatic reasoning based on knowledge. After finishing considering the new increased feature’ impact on this product’s processing, we need design the processing and procedure. And to the processing design, we mainly consider the insertion point of the new increased feature and the final sequence of the procedure. However, to the processing design, we mainly consider the choosing of all kinds of parameters and the processing scheme when designing the process.

3 Research of classified code system based on feature

CAPP is a key link in the integration of CAD/CAM. Since sixties, CAPP has got swift development, which becomes a new computer application technology^[16-18]. Initial CAPP is based on group technology, generally called GT. To GT, it demands that write the products information and the code of processing technique in advance, and then classify the products according to certain algorithm, finally get the products clan and its clan matrix. This method can only express shape feature, which seems incompletely flexible for showing the processing feature and function feature and not suitable for the integration based on CAD/CAPP/CAM of the feature. In order to realize the integration based on CAD/CAM of the feature, we must adopt a new kind of classified code system——classified code system based on feature. To work out this kind of system, we should extract feature according to the given product at first, then classify and code it.

3.1 Drawing the processing feature of composite

3.1.1 Principle for drawing the processing feature of composite

It is generally acknowledged when drawing the processing feature of composite; we should keep to the following principles:

- (1) Should reflect the intention of the designer and manufacturer to the best in order to be convenient for use

Design feature means the meaningful characteristic to design process, and manufacturing feature refers to the meaningful characteristic to the manufacture process. Design feature is that in design process, the designer, from the angle of meeting the request of products’ function and performance, work out one pieces of “function feature” to form the shape of products. It reflects the designer’s design intention. However, manufacturing feature, defined from the angle of product process, reflects the feature of certain processing method, that is, using the view of manufacturing, assemble and detection, manufacturing feature is defined to explain and combine the feature of shape. So in the course of drawing the feature of shape, we should consider design feature and manufacturing feature at the same time.

(2) Drawing the shape feature should have commonality

Drawing the shape feature should have commonality, which should include more products, thus increase systematic adaptability. However, to the complicated products, it can define the special feature, reduce systematic complexity, simplify the modeling course, avoid describing every simple basic shape tediously, and thus raise the efficiency.

(3) Notice the crossing question of the feature of different drawn products

Drawing features is carried on the basis of 11 major kinds of products. But unavoidably, different products may be drawn the same feature. So we adopt subordinate feature to distinguish them.

3.1.2 Practice drawing the feature

It is important of drawing the shape feature to realize the systematic design based on feature. Moreover, people confine their study in its application occasions and the types of each product at present. And there have no one generally suitable and practical result of the drawn feature yet. So when we establish the classified code system based on feature, it is necessary to draw the shape feature and set up its own shape feature.

In the course of drawing the shape feature, after browsing and analyzing project and process file of eleven kinds of typical products, we combine the practical conditions and analyze the structure feature of products carefully, finally set up a set of classified code system based on feature^[19-20].

This code system has 15-bit code. The first bit is class of composite's identification. According to the feature of composite, it is divided into 11 big classes, separately representing 1 to 11 as plane plate, I-shaped, well shape, cuboids, cube, taper cone, spheroid, round cylinder, cone, annulus, irregular form; The second to the fourth bit represent the main feature: the second bit is the main feature area, the third refers to divide the main features of eleven classes, for example the feature of plane plate contain the feature of other shape; The fourth classifies the feature further, for example the description to other shape; The fifth to the seventh represent the subordinate, and the concrete conditions just like the main feature, the fifth is subordinate feature area, the sixth to seventh classify the subordinate feature further; The eighth is the relationship of the main and subordinate feature, 0 represents having no subordinate feature, 1 and 2 separately represent concave and convex feature that the subordinate feature is relative to the main feature; the ninth identifies the basic material feature of composite, and using 00 to 99 represent different materials; the tenth identifies the reinforced feature of composite, using 00 to 99 express reinforced material; the 11th is the auxiliary materials of composite, using 00 to 99 show the auxiliary materials; the 12th is the strength grade of composite products, expressed by A to Z; the 13th is the modulus grade of composite products, expressed by A to Z too; the 14th is the fracture extensibility grade, expressed by A to Z as well; to reduce the number of the code, the 12th, 13th and 14th identified by letter; the 15th is the size grade, expressed by 0 to 9.

The above shows the classified code system based on feature. And in order to try to reduce the number of code, we mix letter and figure: using 0 to 9 represent the included item less than 10 in the bit code, and using A to Z represent the included item less than 26 in the bit code, however using figure 1 to 9 and letter A to Z concurrently represent the included item less than 35. For example, in the above code system, the second and the fifth use the way. In addition, on the bit of main and subordinate feature, we adopt the classified method with hierarchy, which is not favorable to the classified code of feature of the part, but also the expansion of feature.

3.2 Classified method of the composite products

It is essential how to classify composite, for the various composite products. And the basic request is how to express all products' information rationally, which can be accepted and processed by computer. At ordinary classified foundation, utilizing the conception of fuzzy set gets the fuzzy classification to the composite. Lou put the conception of fuzzy classification forward, and it is the sum of squares' minimization of the distance between all products and the center of classification^[21]. The sample x_i in the set of classified object belongs to some classification under definite membership grade $\mu_A(x_i)$, namely, all composite products belongs to some classification under different membership grade. So, every classification is considered a

fuzzy subset under range U. Corresponding classified matrix by such a classified result is one fuzzy matrix T.

$$T = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ u_{21} & u_{22} & \cdots & u_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ u_{c1} & u_{c2} & \cdots & u_{cn} \end{bmatrix}$$

Hereinto,

(1) $0 \leq u_{ij} \leq 1$, the value of the element of classified matrix is between 0 and 1;

(2) $\sum_{i=1}^c u_{ij} = 1$, that is the sum of membership grade that in every column respectively

belongs to corresponding class. And to a composite product, the sum of the membership grade of its class is 1;

(3) $\sum_{j=1}^n u_{ij} > 0$, this condition ensures that every class must have a product, that is, some

products belongs to every class to different extent.

Assuming the set of the classified objects is $u = \{u_1, u_2, \dots, u_n\}$, hereinto, every product have m kinds of feature. And assume c is the reference vector.

Reference sample is expressed by V_i

$$V_i = (v_{i1}, v_{i2}, \dots, v_{ip})$$

Hereinto,

$$v_{ik} = \frac{\sum_{j=1}^n u_{ij} \times \mu_k(x_{jk})}{\sum_{j=1}^n u_{ij}}$$

Assuming the distance between product j and the reference sample is:

$$\left\{ \sum_{k=1}^p (\mu_k(x_{jk}) - v_{ik})^2 \right\}^{\frac{1}{2}} \quad (1)$$

The weight sum of squares of the distance between all products and reference sample is:

$$J(u, v) = \sum_{j=1}^n \sum_{i=1}^c u_{ij} \sum_{k=1}^p (\mu_k(x_{jk}) - v_{ik})^2 \quad (2)$$

To increase the distance among reference sample, the weight m ($m > 1$) can be written:

$$J_m(u, v) = \sum_{j=1}^n \sum_{i=1}^c u_{ij}^m \sum_{k=1}^p (\mu_k(x_{jk}) - v_{ik})^2 \quad (3)$$

The algorithm of function of the sum of the minimum distance is:

$$u_{ij} = 1 / \sum_{l=1}^c \left(\frac{\sum_{k=1}^p (\mu_k(x_{jk}) - v_{lk})^2}{\sum_{k=1}^p (\mu_k(x_{jk}) - v_{lk})^2} \right)^{\frac{1}{(m-1)}} \quad (4)$$

Assuming the last matrix is:

$$U^* = \begin{bmatrix} u_{11}^* & u_{12}^* & \cdots & u_{1n}^* \\ u_{21}^* & u_{22}^* & \cdots & u_{2n}^* \\ \vdots & \vdots & \vdots & \vdots \\ u_{c1}^* & u_{c2}^* & \cdots & u_{cn}^* \end{bmatrix}$$

If $u_{ij}^* = \max_{1 \leq k \leq c} \{u_{kj}\}$, this product x_j belongs to the class i .

The flow diagram of composite fuzzy classification based on feature shows as figure 2:

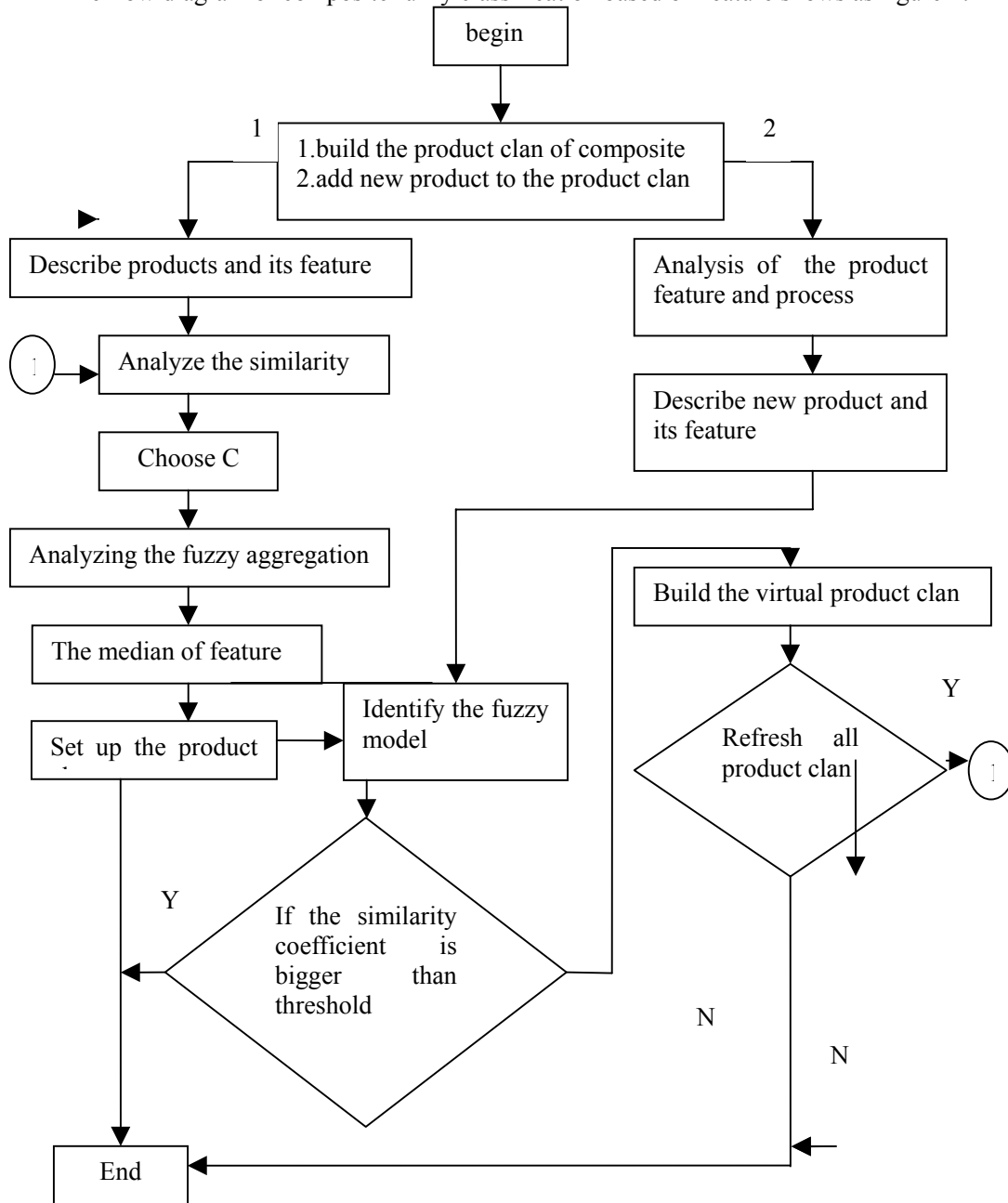


Figure 2. The flow diagram of composite fuzzy classification based on feature

3.3 Application instance

We have already expounded the basic conception and algorithm procedure of fuzzy classified method, and next we will use instance to prove its feasibility and validity of this method

In the course of designing group technology in composite CAPP system, we code the composite products at first, and then divide them into several product clans. The specific algorithm shows as following:

- Input the products code: take 18 composite products at random as an example, input its classified code of the product, like table 1.
- Standardize and deal with the products code, set up the data matrix of fuzzy sample.
- Confirm categorical value c .

- (d) Fetch iterative precision: $\varepsilon=0.001$.
(e) Calculate the membership grade of all products to the cluster center.
(f) Calculate every cluster center, like table 2.
(g) Calculate the membership grade of all products to every new cluster center.
(h) Compare the corresponding element of two matrixes. If it is right, the classification is over, otherwise, iterate repeatedly until it satisfies the criterion of iteration.
(i) Print the result, like table 3.

Table 1 input

Order number	Code element	Order number	Code element
1	110000002513211	11	420013011321231
2	110000002522311	12	420013012331121
3	110000002525431	13	620021113213321
4	110000002532211	14	620021123222211
5	110000002534321	15	620021123332311
6	230000003124311	16	620021123431121
7	230000003233211	17	810011014345531
8	230000003243221	18	810022014356541
9	230000003334321	19	810024014456651
10	420013011312131		

Table 2 classification

Order number	Code element
C1	110000002525431
C2	230000003243221
C3	420013011321231
C4	620021123332311
C5	810022014356541

Table 3 result

Order number	C1	C2	C3	C4	C5
1	*0.351143	0.309874	0.177139	0.158905	0.153135
2	*0.351025	0.309821	0.177162	0.158946	0.153154
3	*0.351025	0.309821	0.177162	0.158946	0.153154
4	*0.350073	0.309727	0.177185	0.158987	0.153204
5	*0.350073	0.309727	0.177185	0.158987	0.153204
6	0.312578	*0.337626	0.186439	0.164109	0.163423
7	0.312571	*0.337609	0.186452	0.164123	0.163457
8	0.312571	*0.337609	0.186452	0.164123	0.163457
9	0.312563	*0.337588	0.186487	0.164165	0.163485
10	0.248179	0.227310	*0.311055	0.198730	0.185736
11	0.248179	0.227310	*0.311055	0.198730	0.185736
12	0.248172	0.227303	*0.311062	0.198738	0.185742
13	0.167594	0.158691	0.193528	*0.251730	0.215936
14	0.167584	0.158687	0.193532	*0.251735	0.215941
15	0.167581	0.158685	0.193535	*0.251738	0.215945
16	0.167572	0.158679	0.193547	*0.251742	0.215951
17	0.107862	0.125362	0.202731	0.228795	*0.233097
18	0.107286	0.125109	0.202785	0.228810	*0.233281
19	0.106819	0.124971	0.202839	0.228917	*0.233476

From table 3, we can find out the distribution of the membership grade of composite products to the cluster center, which accord with actual conditions. Namely, they respectively belong to the plane plate class, I-shaped class, cuboids class, taper cone class and round cylinder class.

4 Conclusions

In sum, this paper realizes the composite CAPP automatic manufacturing technology, thus achieve the goal of reducing the manufacturing cost. This automatic system is set up with computer control for center, and multiple operation unit for the complement, make technological parameter that CAPP produces send to the corresponding operation unit, and in the meanwhile, gather the status information in the forming process by the real-time monitoring system, finish closed-loop control of product-making process, and implement the automation of composite manufacture.

Because the application in the composite field of CAD is first realized, we initially discuss the group technology used in the composite manufacturing, thus we need using various kinds of methods to analyze and prove its practicability. This paper proposes a kind of new progressive processing method based on feature prototype. The prototype of products' technological process could reflect processing design better. In addition, we have proven it is a feasible application that utilizing fuzzy classification based on feature analyzes the composite code of products. It is favorable to the classified code of products' feature, and helps to expanse system as well, which lays the solid foundation in setting up the automatic manufacturing system of composite based on CAPP.

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