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EVALUATION AND SELECTION OF SOME MANUFACTURING TECHNOLOGIES USING THE AHP METHOD

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Abstract: *In industrial practice, there are situations in which it is necessary to select a technology from several manufacturing technologies for a product. One of the methods that can be used in this regard is the analytic hierarchy process method. Using the method involves identifying and weighing some selection criteria. Subsequently, the composite weights of each of the technologies taken into account are determined based on each of the identified criteria. The method was applied to select a technology for separating samples from a workpiece in the form of a plate. It was considered that the separation can be achieved by classical technologies and, respectively, by some non-conventional technologies, such as wire electrical discharge machining, laser beam machining, and plasma beam machining. For the conditions considered, it was found that the most convenient technology is the one based on the use of a plasma beam.*
Keywords: *analytic hierarchy process method, classical technology, wire electrical discharge machining, laser beam machining, plasma beam machining, selection criteria.*

1. INTRODUCTION

One of the current meanings of the concept of technologies concerns entities generated through problem-solving processes, solved through transformations following ideas initially formulated in the form of plans or projects and intended to develop a certain artificial function [1].

In the field of machine manufacturing, the concept of technology usually refers to the manufacture of a part or mechanical equipment in whose structure electrical, electronic subsystems, etc. are sometimes included.

Manufacturing technologies are important primarily because they are the ones that exert a decisive influence on the cost of the product and therefore on the selling price.

In the case of a company that is to be built, the establishment of some principled manufacturing technologies is necessary to know what manufacturing equipment is to be purchased. In the case of an existing company, manufacturing technologies are largely established by taking into account existing equipment.

When the issue of manufacturing a part arises, it is necessary to develop a so-called *manufacturing process*.

The concept allows for the consideration of optimization and monitoring actions for the manufacturing of the respective parts. Knowledge of the manufacturing technology of a part facilitates the calculation of the manufacturing cost of the product and, ultimately, the estimation of its selling price.

According to a management principle, when for an important problem there seems to be only one solution to solve it, there is a high probability that that solution is not the best [2].

Applying such a principle in the design of the manufacturing technology of a part may make it necessary to develop several technology variants, and then, by using appropriate criteria, the most convenient manufacturing technology is selected.

The problem of selecting a manufacturing technology from several available technologies has been a concern for researchers in the field of mechanical engineering.

Thus, Hamzeh and Xu found a continuous increase in studies aimed at using methods for selecting manufacturing technologies during the period 1990-2017 [3]. They considered that the methods for evaluating or selecting technologies can be single approaches or hybrid approaches.

Peko et al. used the AHP method to select an additive manufacturing process taking into account 3 processes, namely 3D printing, fused deposition modeling, and selective laser sintering [4].

Swat et al. showed that it is necessary for the selection of a particular manufacturing process to take into account environmental requirements, for example by minimizing the energy consumption required by the manufacturing process [5].

In this paper, the problem of selecting a technology for separating tensile test specimens from a workpiece in the form of a plate was considered.

The analysis of the processing conditions highlighted the existence of 4 distinct technologies, from which it is necessary to choose the most suitable technology, by using 5 selection criteria. Subsequently, by using the analytic hierarchy process method, it became possible to determine, for each of the technologies, a general composite weight, which allowed the justified selection of the most suitable technology.

2. ESTABLISHING THE MANUFACTURING TECHNOLOGY OF A PART

One of the first stages of the design process of a manufacturing technology refers to the principled establishment of a certain sequence of processing (processing operations) so that the manufacturing process leads to the generation of a product following the prescriptions in the design documentation, at a minimum cost and within the time frame allocated for the manufacture of the product.

It can thus be noted that two of the criteria that must be taken into account when selecting a certain manufacturing process are the cost of the product and the duration of its manufacture.

As initial information for the manufacture of a product, the requirements mentioned in the product design documentation, the volume of production, the technological equipment available and necessary for the manufacture of the product, the level of professional qualification of the operators available and involved in the manufacture of the product, the requirements for occupational safety and environmental protection, etc. are considered.

The criteria that can be used to select the most suitable manufacturing technology could be the following:

a) The probability that the product can be manufactured following its design requirements;

b) Manufacturing cost;

c) Product manufacturing time;

d) Costs of tools, devices, and testers needed to be used in the manufacturing process;

e) Energy required to perform various operations;

f) Cost of the workpiece;

g) Possibilities of automating the manufacturing process;

h) Cost of designing the manufacturing technology, etc.

It can be easily seen that at least some of the criteria mentioned above are also factors capable of influencing the process of selecting the most suitable manufacturing technology, among several manufacturing technologies that can be used.

On the other hand, there are distinct methods that can be applied to select the most suitable manufacturing process for a part and some such methods are: mathematical programming, analytic hierarchy process method, fuzzy logic, data envelopment analysis (DEA), financial analysis, technique for order preference by similarity to ideal solution (TOPSIS), preference ranking organization method for enrichment evaluation (PROMETHEE), conceptual frameworks, dynamic programming [6], etc.

It can be observed that identifying the most suitable manufacturing technology *constitutes a decision problem* or, more specifically, a problem of making an optimal decision.

It is known that a classification of decisions based on the circumstances in which the respective decisions are formulated takes into account decisions with preferential individual applicability and group decisions, respectively. In turn, decisions with preferential individual applicability can be decisions that are made under conditions of certainty (and this is usually the case of selecting a certain technology among several available technologies), decisions that can be adopted under conditions of risk, and decisions that are made under conditions of uncertainty [6].

On the other hand, when the activity of selecting the optimal variant takes into account a single criterion, it is a single-criteria optimization, unlike the case of the need to use several criteria, when it is necessary to apply a *multi-criteria optimization* (multi-objective optimization or multi-attribute optimization).

3. METHOD OF THE ANALYTIC HIERARCHY PROCESS

It is considered that the analytic hierarchy process method is based on mathematical and sychological considerations, respectively. The person who initially promoted the method was Thomas L. Saaty, during the period when he was a professor at the University of Pittsburgh (United States of America).

The name of the method is related to the fact that solving the optimization problem starts from a certain hierarchy of the different aspects that are approached successively [6-8].

Applying the method involves going through several stages, the most important stages being the following:

1. Designing a model of the problem, to highlight the objective that needs to be met, the variants that can be applied, and, respectively, the criteria that can be used to evaluate the available variants;
2. Identifying priorities, by resorting to comparing the evaluation criteria and the available variants two by two;
3. Elaboration of a synthesis that will reveal the hierarchy of the analyzed variants;
4. Testing the extent to which the evaluations are coherent;
5. Formulation of the final decision.

In recent decades, the analytic hierarchy process method has been applied to solve a wide range of problems in different areas of economic and social life.

4. APPLICATION OF THE AHP METHOD FOR SELECTING A MANUFACTURING TECHNOLOGY OF A PART

The need to select a manufacturing technology for a set of 10 specimens required for tensile tests to test the mechanical strength of the specimen material (medium carbon steel) is considered.

The use of a workpiece in the form of a plate with a thickness of 3 mm is envisaged.

The specimens are to be subjected to heat treatments, intending to monitor the influence of some input factors in the heat treatment process on the mechanical strength of the specimen material. The shape of the specimen is shown in Figure 1.

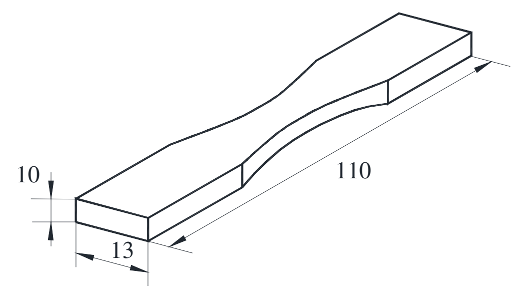

Fig. 1. Main shape and dimensions of medium carbon steel specimen for tensile testing.

The objective pursued by applying the AHP method refers to the selection of the most convenient variant of materializing processing or a set of processing operations through which, from the workpiece in the form of a steel plate, the necessary specimens for the subsequent development of tensile tests are separated [9-12].

Assuming that the workpiece exists, the main technological problem is the detachment from the workpiece of a part with a shape as close as possible to the final shape of the specimen. The main operations for manufacturing the specimen could be the following:

1. Separation from the workpiece of specimens with a shape close to the final shape

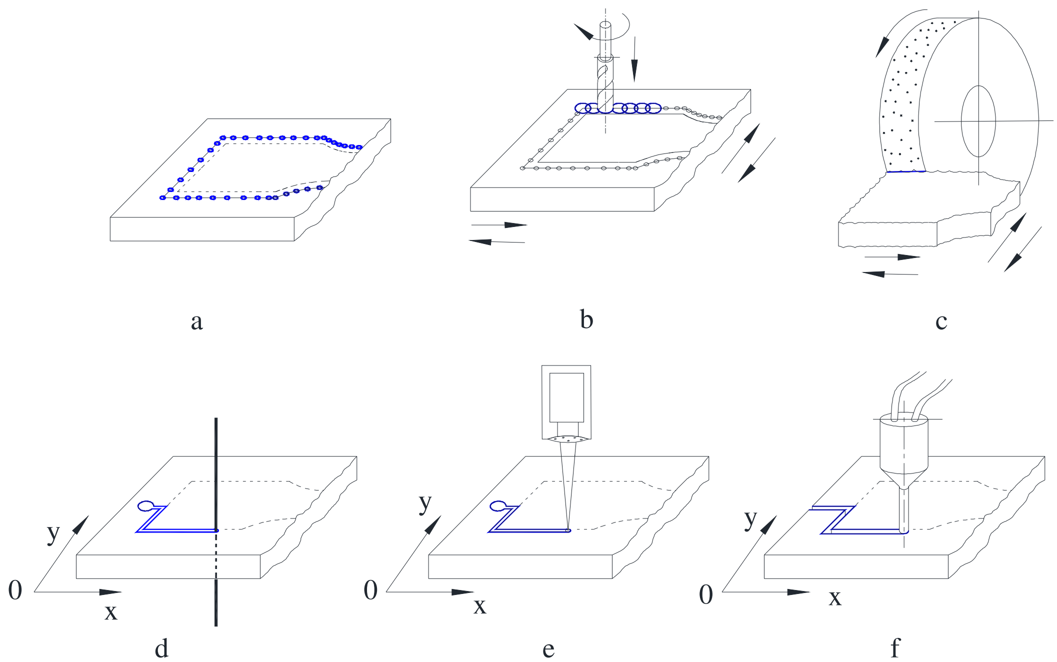

Fig.2. Marking (a), drilling (b), and polishing (c) surfaces in the case of a classic technology for separating a specimen from a steel plate-type workpiece; wire-electrode discharge cutting (d), laser beam cutting (e), and plasma beam cutting (f).

of the specimen recommended for performing tensile tests;

2. Application of possible surface finishing processes resulting from the detachment of the specimen from the workpiece;

3. Application of heat treatments and operations recommended after heat treatments;

4. Final technical control.

From the aforementioned technological route, it can be seen that at least four distinct technologies can be considered for detaching a part with a shape as close as possible to that of the final specimen from the workpiece in the form of a plate. These technologies can be based on (fig. 2):

Alternative A1: use of classical cutting processes (CM). It will include making holes that will partially overlap, so that it is possible to separate a raw specimen, and subsequently, through grinding, filing, milling, etc. operations, the raw specimen will be brought to the desired final shape. The application of these classical processes mentioned still implies the prior performance of a tracing operation and possibly the execution of centering holes, which will allow rapid positioning of the drill in line with the axis of the hole to be made;

Alternative A2: using wire electrical discharge machining (WEDM). The removal of material along the contour to be obtained is carried out by electrical discharges and by the circulation of a dielectric liquid. The wire electrode has a diameter of about 0.01-0.3 mm. The speed of movement of the wire electrode along the contour is about 6-180 mm/min. The dimensional accuracy is quite high, and the roughness of the surface generated by the processing is low, so it may not be necessary to apply further processing.

Alternative A3. using laser beam machining (LBM). The removal of material from the workpiece occurs as a result of the melting and vaporization of the workpiece material by a thin laser beam and, respectively, by a pressurized gas jet sent along a direction coinciding with the axis of the laser beam. In the case of steel workpieces, the speed of movement of the laser spot can have values of 1200-2400 mm/min. Currently, sufficiently precise surfaces with low roughness can be obtained, so that additional subsequent processing is not necessary.

Alternative A4: use of plasma beam machining (PBM). The removal of material from the workpiece occurs as a result of the action of a thin plasma jet produced using a plasma generator. In current versions, the width of the slit generated by the action of the plasma jet has values of 0.4-10 mm, which means that the amount of material detached as waste is greater than that of laser beam cutting. The speed of movement between the plasma jet and the workpiece has values of 0.1-1000 m/min, being, therefore, greater than that of wire-electrode electrical erosion processing and laser beam cutting. The last three categories of processing also contribute to a significant thermal modification of the surface layer generated by processing, to a smaller thickness in the case of wire-electrode electrical erosion processing, to a somewhat larger thickness in the case of laser beam cutting, and an even greater thickness in the case of plasma beam cutting. Since the steel specimens are to be subjected to predetermined heat treatments, it was considered that this initial modification of the structure generated by the previously applied process should not be taken into account as a criterion for selecting the technology for cutting the specimen from the workpiece in the form of a steel plate with medium carbon content.

It is considered that the necessary equipment exists to materialize each of the 4 technologies considered.

5. COMPARISON OF TECHNOLOGY SELECTION CRITERIA

The criteria that will be applied to select the most suitable technology for separating the samples from the workpiece in the form of a steel plate will be:

Criterion C1: processing cost. It was assessed that the most expensive processing could be laser beam cutting, while the cheapest could be processed by classical processes, the latter technology not involving the use of complicated and expensive equipment.

Criterion C2: processing time, which provides an idea of the material removal rate from the workpiece, i.e., the processing productivity.

It was considered that the highest productivity could be obtained by plasma beam processing and that processing by classical methods, respectively, by wire electrical discharge machining, would require the longest durations, while the fastest processing method would be plasma beam cutting;

Criterion C3: the need (and cost) for a greater or lesser number of tools, devices, and testers. It was assessed that plasma cutting would require less tooling, while wire EDM machining would require additional locating-clamping devices, therefore more complex and, as such, more expensive tooling;

Criterion C4: the need to use operators with high professional qualifications. It was assessed that in the case of wire EDM, laser beam, and plasma beam cutting, it is necessary to use equipment with numerical control subsystems. Such equipment requires the presence of

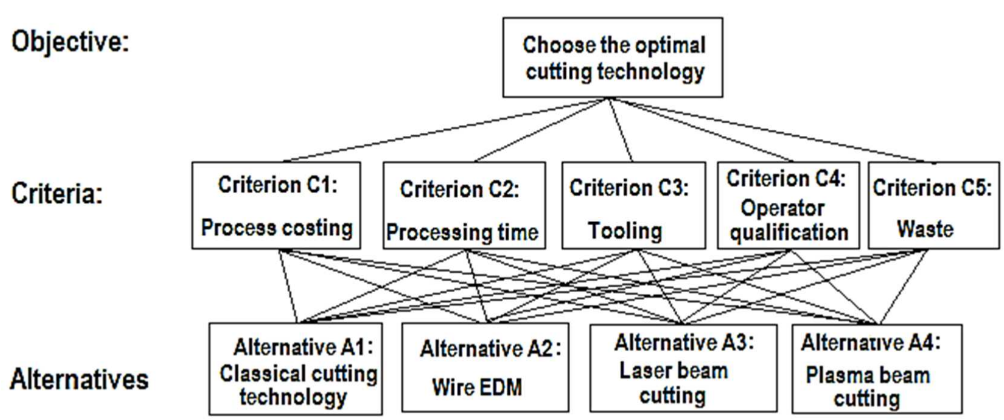

Fig. 3. AHP hierarchy valid in case of the need to select a technology among 4 available technologies.

operators with higher qualifications, while machining by classical processes would require operators with lower qualifications.

Criterion C5: loss of material in the form of recoverable waste.

The largest amount of material removed in the form of chips by drilling and grinding will correspond to processing by classical processes, while the narrowest gap, therefore the lowest losses in the form of reusable waste, will be obtained in the case of cutting by wire electrical discharge machining.

The graphic representation in Figure 3 highlights the so-called *AHP hierarchy*. The zero level of this graphic representation corresponds to the objective of the analysis, namely that of selecting a technology (of a process or several machining processes) for the separation of the 10 specimens from the workpiece in the form of a steel plate.

Continuing the application of the first stage of the AHP method, Table 1 was developed, which included the criteria taken into account and the results of comparisons of the respective criteria.

The results of the pairwise comparison of the selection criteria can be seen in Table 1.

In columns 7-10, "X" symbols were entered when a processing criterion was considered to be 2, 3, or 4 times more important than the criterion with which it is compared.

As can be seen, there were no situations where two criteria were considered equal from the point of view of the criteria subject to analysis, and no "X" symbol was included in column 7.

The number n_c of pairwise comparisons of criteria can be determined using a relationship of the form:

$$n_c = \frac{n(n-1)}{2}, \tag{1}$$

where n is the number of criteria taken into account. For the n=5 criteria taken into account, it is found that 10 comparisons are necessary.

To perform the comparisons, the software proposed in [13] was used, with the help of which the weights of the criteria were determined. The results obtained were synthetically presented in Table 2. It can be seen

Table 1

Comparing two by two evaluation criteria and assigning scores.

Line No. 1	**Is A more important or B?**					**Equality**	**How many times is it more important**							
2	***A***		**or**	***B***		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Line No. 3 Col-umn No. 1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Line No. 4	*X*	Processing cost (*C*1)	or		Processing time (*C*2)		*X*							
5	*X*	Processing cost (*C*1)	or		Tooling (*C*3)			*X*						
6	*X*	Processing cost (*C*1)	or		Operator qualification (C4)				*X*					
7	*X*	Processing cost (C1)	or		Waste (*C*5)					*X*				
8	*X*	Processing time (*C*2)	or		Tooling (*C*3)		*X*							
9	*X*	Processing time (*C*2)	or		Operator qualification (*C*4)			*X*						
10		Processing time (C2)	or		Waste (C5)				*X*					
11	*X*	Tooling (*C*3)	or		Operator qualification (*C*4)		*X*							
12	*X*	Tooling (C3)	or		Waste (C5)			*X*						
13	*X*	Operator qualification (C4)	or		Waste (C5)		*X*							
14	The AHP scale was as follows: 1 – equal importance; 3 – moderate importance; 5 – high importance; 7 - very high importance; 9 - extreme importance (values 2, 4, 6 and 8 being intermediate values)													

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that, according to the results in this table, the analysis of the importance of the selection criteria led to the following order:

1. Processing cost;
2. Processing duration, determined according to the regulations on labor standardization;
3. Required tooling;
4. Qualification level of the operators involved;

Table 2

Weights for criteria.

Cat	Priority	Rank	Weight, %
1	Processing cost	1	41.9
2	Processing time	2	26.3
3	Tooling	3	16.0
4	Operator qualification	4	9.7
5	Waste	5	6,2

5. Material losses are generated by the application of each of the technologies (processes) used.

In Table 3, the values corresponding to a matrix resulting from the comparison of two criteria were entered; in this matrix, the 5 criteria taken into account were entered, both along the first line and the first column.

Table 3

Decision matrix.

	*C*1	*C*2	*C*3	*C*4	C5
*C*1	1	2,00	3,00	4.00	5.00
*C*2	0,50	1	2,00	3.00	4.00
*C*3	0.33	0.50	1	2.00	3.00
*C*4	0.25	0.33	0.50	1	2.00
C5	0.20	0.25	0.33	0.50	1

In the spaces in the table, the values were entered that highlight the number of times a selection criterion was considered more or less convenient than the criterion with which it is compared. The values entered in Table 2 can be deduced with relative ease from the information included in Table 1.

6. COMPARISON OF THE TECHNOLOGIES TAKEN INTO CONSIDERATION

The next stage of applying the AHP method requires comparing the technologies considered.

The results obtained by comparing the technologies for separating the samples from the workpiece in the form of a plate, for each of the 5 evaluation criteria, were synthetically presented in Table 4.

The columns of this table included the symbols of the technologies considered (column 2), the results of the comparisons (in columns 3-6, proceeding similarly to that used to develop the decision matrix in Table 3), the weights of each alternative corresponding to a certain criterion (column 7) and respectively the order of the alternatives when using each criterion (column 8).

With the information included in Tables 2 and 4, it became possible to determine the general composite weights, listed in Table 5.

Such a general composite weight of each of the 4 technologies considered is determined as a sum of the products of the weight of each criterion with the weight of the technology when using the respective criterion. There will therefore be sums of four products, ultimately obtaining:

$$A1= 41.8\cdot 41.9+15.1\cdot 26.3+17.9\cdot 16 +40\cdot 9.7+9.5\cdot 6.2=2855.55=28.5555\ \% \quad (2)$$

$$A2= 27.1\cdot 41.9+14.1\cdot 26.3+13.8\cdot 16.0 +20\cdot 9.7+46.7\cdot 6.2=2210.66=22.1066\ \% \quad (3)$$

$$A3= 12\cdot 41.9+26.3\cdot 26.3+32\cdot 16+ 20\cdot 9.7+27.7\cdot 6.2=2072.23=20.7223\% \quad (4)$$

$$A4=19.1\cdot 41.9+45.5\cdot 28.3+36.3\cdot 16 +20\cdot 9.7+16\cdot 6.2=2870.94=28.7094\ \% \quad (5)$$

Based on these results (entered in the penultimate column of Table 5), it can be seen that by taking into account the general composite weights of the four technologies susceptible to use, the order of the respective technologies is as follows:

1. Plasma beam cutting (general composite weight of 28.70);
2. Processing by classical technologies (general composite weight of 28.55);
3. Cutting by wire electrical discharge machining with (a general composite weight of 22.10);

4. Cutting with a laser beam (general composite weight of 20.72%).

The values of these general composite weights highlight the fact that the technology that should be preferred for the detachment of specimens from the workpiece in the form of a steel plate is the one that uses the plasma beam, which corresponds to the highest value of the general composite weight.

7. CONCLUSIONS

One of the methods for selecting an alternative from several available alternatives is the analytic hierarchy process method. The use of the method involves first identifying selection criteria and then weighing these criteria. Subsequently, the alternatives are compared two by two by taking into account each of the previously established criteria. A general composite index is further calculated as a sum of the products of the weight of each criterion with the weight corresponding to the alternative within each of the criteria. The method was applied for the argumentative selection of the technology for separating some specimens for tensile tests from a plate-type workpiece of a determined thickness. 4 separation technologies were identified and 5 selection criteria were used. Finally, it was found that the most

Table 4

Calculation of the weight of each processing method for each of the 5 evaluation criteria.

Line 1 Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
Line 2	Criterion *C*1 – Processing cost						
3	Processing method	CM	WEDM	LBM	PBM	Priority vector	Order
4	CM	1	2	3	2	41.8	1
5	WEDM	0.5	1	2	2	27.1	2
6	LBM	0.33	0.50	1	0.50	12.0	3
7	PBM	0.50	0.50	2	1	19.1	4
8	Criterion *C*2 – Processing time						
9	Processing method	CM	WEDM	LBM	PBM	Priority vector	Order
10	CM	1	1	0.5	0.33	14.1	3
11	WEDM	1	1	0.5	0.33	14.1	3
12	LBM	2	2	1	0.5	26.3	2
13	PBM	3	3	2	1	45.5	1
14	Criterion *C*3 - Tooling						
21	Processing method	CM	WEDM	LBM	PBM	Priority vector	Order
22	CM	1	2	0.5	0.33	17.9	3
23	WEDM	0.5	1	0.5	0.5	13.8	4
24	LBM	2	2	1	1	32.0	2
25	PBM	3	2	1	1	36.3	1
26	Criterion *C*4 – Operator qualification						
27	Processing method	CM	WEDM	LBM	PBM	Priority vector	Order
28	CM	1	2	2	2	40.0	1
29	WEDM	0.5	1	1	1	20.0	2
30	LBM	0.5	1	1	1	20.0	2
31	PBM	0.5	1	1	1	20.0	2
32	Criterion *C5* - Waste						
33	Processing method	CM	WEDM	LBM	PBM	Priority vector	Order
34	CM	1	0.25	0.33	0.50	9.5	4
35	WEDM	4	1	2	3	46.7	1
36	LBM	3	0.50	1	2	27.7	2
37	PBM	2	0.33	0.50	1	16.0	3

Table 5

General composite weight for each cutting technology.

Criterion	***C*1**	***C*2**	***C*3**	***C*4**	***C*5**	**General composite weight**	**Final order**
Criterion weight / Processing method	41.9	26.3	16	9.7	6.2		
CM	41.8	14.1	17.9	40	9.5	28.5555	2
WEDM	27.1	14.1	13.8	20	46.7	22.1066	3
LBM	12	26.3	32	20	27.7	20.7223	4
PBM	19.1	45.5	36.3	20	16	28.7094	1

convenient technology is the one based on a plasma beam-cutting process. In the future, it is intended to apply the method also in the case of the need for optimal selection of other possible technologies to be used, from several available technologies.

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Evaluarea și selectarea unor tehnologii de fabricație folosind metoda AHP

În practica industrială, există situații în care este necesară selectarea unei tehnologii dintre mai multe tehnologii de fabricare a unui produs. Una dintre metodele utilizabile în aceste sens este metoda procesului de ierarhizare analitică. Utilizarea metodei implică identificarea și ponderarea unor criterii de selecție. Ulterior, se determină ponderi compozite ale fiecăreia dintre tehnologiile luate în considerare plecând de la fiecare dintre criteriile identificate. Metoda a fost aplicată pentru selectarea unei tehnologii de separare a unor epruvete dintr-un semifabricat sub formă de placă. S-a considerat că separarea se poate realiza prin tehnologii clasice și respectiv prin unele tehnologii neconvenționale, așa cum sunt prelucrarea prin eroziune electrică cu electrod filiform, prelucrarea cu fascicul laser, prelucrarea cu fascicul de plasmă. Pentru condițiile luate în considerare, s-a constatat că, cea mai convenabilă tehnologie este cea bazată pe utilizarea unui fascicul de plasmă.

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