Choice of the Optimal Pareto Composition of the Charge Material for the Manufacture of Composite Blank

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Abstract. The results of an experimental study of the mechanical properties of pressed and sintered briquettes consisting of powders obtained from a high-strength VT-22 titanium alloy by plasma spraying with additives of PTM-1 titanium powder obtained by the hydride-calcium method and powder of PV-N70Yu30 nickel-aluminum alloy are presented. The task is set for the choice of the optimal charge material composition of a composite material providing the required mechanical characteristics and cost of semi-finished products and items. Pareto optimal values for the composition of the composite material charge were obtained.

INTRODUCTION

Titanium-containing materials are used in many areas of industrial production [1]. At the same time, the production of such materials is characterized by high energy consumption and a significant amount of difficult-to-process waste from the titanium metallurgical production [2]. Powder metallurgy, which makes it possible to significantly reduce the material consumption of products and the volume of machining, is a widespread method of recycling metallurgical wastes [3]. At the same time, prospects for creating new composite materials with unique properties are opened [4].

When creating composite materials, the problem arises of choosing the optimal composition of the charge from powdered raw materials. Since the charge components have a different effect on the properties and cost of composite materials, it is required to provide a certain level of characteristics of the products obtained due to the composition variation.

The paper presents the formulation and solution of the problem of determining the optimum composition of the charge for a composite material from powdered raw materials. Briquettes from powder compositions containing titanium industrial production waste processed into powder are used as an object of the research. The Pareto optimal composition of the powder composite is determined.

METHODS OF RESEARCH

The object of the research is a powder composite consisting of a powder obtained from the VT-22 alloy by plasma spraying, with additives of PTM-1 titanium powder obtained by the hydride-calcium method, and PV-N70Yu30 nickel-aluminum alloy powder.

In order to select the powder composite optimal composition for the production of products operating under cyclic force and temperature loads resistant to aggressive media, several series of screening experiments were conducted, the results of which are described in [5].
In this paper, we studied the process of compacting powder mixture obtained from the VT-22 alloy by plasma spraying, with additives of PTM-1 titanium powder obtained by the hydride-calcium method, and PV-N70Yu30

nickel-aluminum alloy powder. The VT-22 alloy powder was chosen to increase the strength properties of the composite material. The test powder is represented by a fraction of less than 440 μm; the average particle size is 156 μm.

The samples were pressed at 1000 MPa. The briquettes were pressed on the MS-500 hydraulic press in a closed folding die mold. After pressing, briquettes with density ρ_{rel} = 0.71…0.85 from theoretical one were obtained. The briquettes are of satisfactory quality. In a number of cases, for the unsintered samples with a VT-22 content of 60% or higher, the lower edge was shed. The pressed samples were sintered in a 10^{-3} MPa vacuum for 2 hours at a temperature of 1200 °C, and then heated to a sintering temperature of 1 hour. The SNVE-9/18 chamber-type vacuum resistance electric furnace was used.

The strength of the briquettes was estimated from the results of the axial compression experiments on the ZWICK VT1-FR050THW/A1K universal testing machine. At the beginning of the blank destruction, the force was fixed and the compressive strength σ_u at the current density was determined.

The results of the experimental study are shown in Table 1. It shows the values of the parameters of compacted and sintered samples for each charge composition.

TABLE 1. Results of pressing a titanium-containing composite material

No.	Varying factors			Optimization criteria		
	X_1	X_2	X_3	Y_1, MPa	Y_2	Y_3, p.u./kg
1	50	50	0	1,350	0.804	3,000
2	50	50	0	1,356	0.806	3,000
3	50	50	0	1,360	0.809	3,000
4	60	30	10	1,101	0.810	2,300
5	60	30	10	1,103	0.812	2,300
6	60	30	10	1,106	0.815	2,300
7	60	20	20	830	0.779	2,100
8	60	20	20	834	0.783	2,100
9	60	20	20	840	0.785	2,100
10	60	10	30	530	0.771	1,900
11	60	10	30	535	0.776	1,900
12	60	10	30	539	0.78	1,900
13	65	25	10	1,052	0.787	2,050
14	65	25	10	1,056	0.789	2,050
15	65	25	10	1,059	0.791	2,050
16	65	15	20	765	0.752	1,850
17	65	15	20	768	0.756	1,850
18	65	15	20	772	0.758	1,850
19	65	5	30	406	0.751	1,650
20	65	5	30	410	0.754	1,650
21	65	5	30	412	0.758	1,650
22	70	30	0	592	0.768	2,000
23	70	30	0	594	0.771	2,000
24	70	30	0	598	0.774	2,000
25	70	25	5	963	0.781	1,900
26	70	25	5	967	0.785	1,900
27	70	25	5	972	0.787	1,900

Table 1 shows the percentages by weight of VT-22, PTM-1, PV-N70Yu30 powders, ultimate compressive strength σ_u, relative density ρ_{rel}, cost index of C feedstock.

As a result, Table 1 X_1, X_2, X_3 shows the variable factors representing the percentage by weight of the charge components: X_1 – the VT-22, X_2 – PTM-1, X_3 – PV-N70Yu30 percentage. The parameters chosen as optimization criteria are designated as follows: Y_1 means σ_u, $Y_2 - \rho_{rel}$, $Y_3 - C$.

RESULTS

The task of optimizing the composite material is as follows: to determine the optimal composition of the charge, in which pressing the noncompact titanium-containing raw material produces a blank with the maximum mechanical properties, with minimal costs for their production.

By the values of the optimization criteria Y_1, Y_2, Y_3 (Table 1), 6 Pareto optimal [6] options were selected (3, 6, 15, 18, 21, 27). The algorithm for selecting the Pareto optimal options is shown in Fig. 1. The construction of a set of Pareto optimal solutions is one of the first stages of a large number of multicriteria optimization methods. According to one of the solution methods, the final choice of the optimal option is made heuristically (based on experience, intuition, non-formalized considerations) by the decision-maker. Another approach is to compile as far as possible the most complete list of criteria and then to exclude non-essential criteria from consideration. We exclude from consideration Y_3 and from the values of the optimization criteria Y_1, Y_2, 2 Pareto optimal options (3, 6) were chosen from 6 options. Based on the values of the optimization criterion Y_3, one Pareto optimal option (6) was chosen from 2 options (1).

We exclude from consideration Y_2 and from the values of the optimization criteria Y_1, Y_3, 6 Pareto optimal options (3, 6, 15, 18, 21, 27) were chosen from 6 options. Based on the optimization criterion values Y_2, one Pareto optimal option (6) was chosen from 6 options (1).

We exclude from consideration Y_1 and from the values of the optimization criteria Y_2, Y_3, 4 Pareto optimal options (6, 15, 21, 27) were chosen from 6 options. Based on the values of the optimization criterion Y_1, one Pareto optimal option (4) was chosen from 6 options (1).

The following Pareto optimal values are obtained: $X_1 = 60, X_2 = 30, X_3 = 10$.

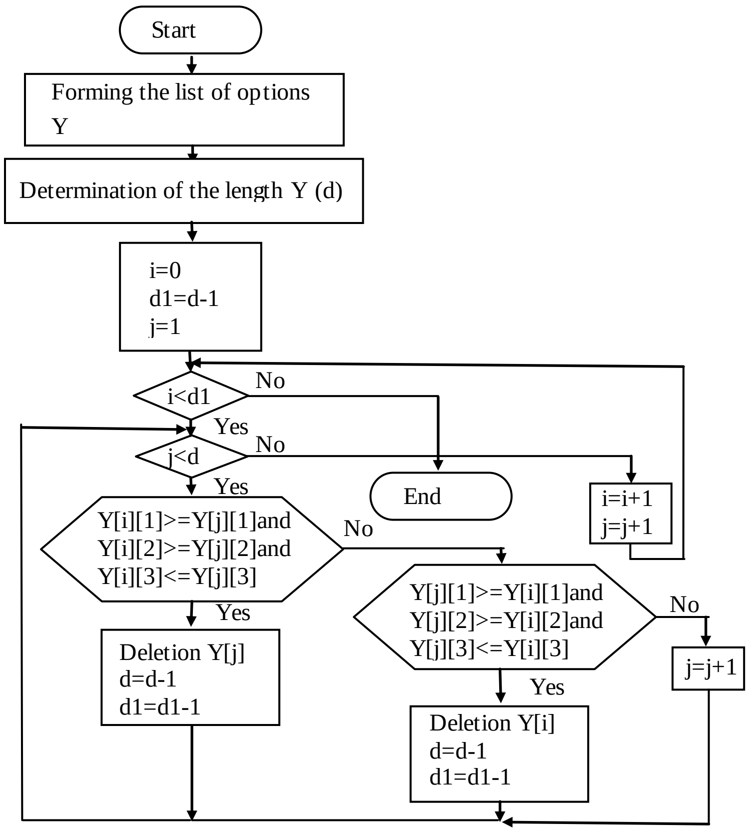

FIGURE 1. The algorithm for selecting the Pareto optimal options

CONCLUSION

Based on the analysis of the experimental data, recommendations are given for choosing the optimum composition of the composite material. For this purpose, a program was developed and a technique was used to optimize the production of a composite of noncompact titanium-containing raw materials, including the search for the Pareto optimal composition of the charge. The following Pareto optimal composition of charge was determined according to this technique: 60% of VT-22 alloy powder, 30% of PTM-1 titanium powder, 10% of PV-N70Yu30 nickel-aluminum alloy powder.

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