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OPTIMIZATION OF THE SQUEEZE CAST Y_2O_3/Al-Si COMPOSITES BY MERIT RATING METHOD

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ABSTRACT

In this paper, Y_2O_3/Al–Si composites are prepared by squeeze casting process and merit rating method is used to optimize the squeeze casting process parameters. A wear rate and hardness tests were conducted and the density is calculated for the resulted castings. The primary objective is to use merit rating method to find a better group of parameters that give the good balance of high density and hardness with low wear rate. The evaluated squeeze casting parameters are pouring temperature, die temperature, and squeeze pressure. The experimental and analytical results showed that the merit rating method was successful in determining the group of parameters that give an optimum balance of properties. Also it showed that if the difference in any property values among specimens is high, it can affect the selection process with the importance sequence.

KEYWORDS: **Optimization; Squeeze casting; composites; Merit rating**.

امثلية متراكبات Y_2O_3/Al-Si المحضرة بطريقة السباكة بالعصر بواسطة طريقة التقييم المستحق

الخلاصة

تم في هذا البحث تحضير متراكبات Y_2O_3/Al-Si بعملية السباكة بالعصر وتم استخدام طريقة التقييم المستحق لايجاد امثلية متغيرات عملية السباكة بالعصر. تم اجراء فحوصات معدل البلى والصلادة وحساب الكثافة للمسبوكات الناتجة. ان الهدف الاساسي هو استخدام طريقة التقييم المستحق لايجاد المجموعة الاحسن من المتغيرات التي تعطي التوازن الجيد من الكثافة والصلادة العالية مع معدل البلى القليل للمسبوكات. متغيرات عملية السباكة بالعصر المقيمّة هي درجة حرارة الصب، درجة حرارة القالب وضغط العصر. اظهرت النتائج التجريبية والتحليلية ان طريقة التقييم المستحق كانت ناجحة في تقييم وايجاد مجموعة المتغيرات التي اعطت التوازن الامثل للخواص. اظهرت كذلك انه اذا كان الاختلاف في قيم اي خاصية بين العينات عاليا فانه يمكن ان يؤثر على عملية الاختيار مع تتابع الاهمية.

الكلمات المفتاحية: الامثلية، السباكة بالعصر، المواد المتراكبة، التقييم المستحق.

INTRODUCTION

Engineers are faced with the problem of selecting materials for the subject design. At present, there are so many materials from which the design or materials engineer must make a selection for a specific design. To add to the confusion, new materials are being developed at an almost unbelievable pace. New materials composites, for example are now engineered to meet specific design requirements rather than adapting the design to existing materials. It is difficult for the materials engineer, who has been educated in the fundamentals of materials behavior, to keep up with all the new developments, and this problem is even more difficult for design engineers [Murray1997, ASM Handbook 1997].

There are many requirements which the material must satisfy. Each candidate material must at least minimally satisfy all the requirements. It is likely that each material will possess some characteristics that exceed the minimum requirements by varying amounts. Thus, we need a method for rating how well each material meets the requirements. Some requirements may be more important than others. Greater weight should be given to the more important requirements. Also the selection of proper materials for a component is a critical engineering activity. It is often governed by many conflicting factors. The decision making in the presence of multiple, generally conflicting criteria is known as multiple criteria decision making (MCDM) [Murray1997, National Research Council1995, Shanian2006].

In general, in the area of decision making trusting the intuition is more common than using any kind of numerical approach. However, in those areas such as materials selection in which there are numerous different choices and many various criteria influencing the selection, a more precise approach would be required [Dehghan2007, Fayazbakhsh2009].

Materials selection for engineering design needs a clear understanding of the functional requirements for each individual component and various important criteria/factors need to be considered. The problem in materials selection is to determine the optimum material where there are a number of required properties and a number of materials meeting the different properties in different ways. The issue is then to determine the material which achieves the best balance of properties. This can be done by optimization which is one of the most important steps in engineering to design and operate the systems by considering the effects of many parameters [Reddy2010, Bolton1998, Yang2003].

A variety of quantitative selection procedures for optimization have been developed to analyze the large amount of data involved in the selection process so that a systematic evaluation can be made. There are many different ideas on how material selection for a product should be made. One way of doing this is the use of merit rating method [Farag2002, Farag1979, Jahazi2004, Jahan2010, Cicek2010, Giaccobi2010].

In this paper, an optimization procedure by merit rating method is used to find the better squeeze cast Y_2O_3/Al-Si composite that have the better balance of evaluated properties.

EXPERIMENTAL WORK

(Al–14% Si) alloy is used as a matrix of the composites. Table (1) shows the chemical composition of the alloy which is conducted by the atomic absorption apparatus at the Ministry of Science and Technology. Y_2O_3 powder with (+50 to –75) micron particle size is used as a reinforcement. A (190 gm) of the matrix alloy is melted at 700°C in an electrical furnace. A (10 gm) of Y_2O_3 powder (5 wt%), is wrapped in pure aluminum foil and heated to 300°C for 30 minutes, then added to the melt. After that, the melt was stirred inside the furnace by an electric mixer equipped with steel fan spin at (500rpm) speed for (3 minutes) to make a vortex in order to disperse the particles in the melt. The squeeze casting die is heated to the required temperatures (100,200,300°C). The preheated die is then placed on the hydraulic press table. The melt temperature was controlled and checked with thermocouple before pouring into the die. The melt temperature was raised to about (5°C) above the required pouring temperature in order to keep the pouring temperature during transportation of the melt to the die. The pouring temperatures that are used for all castings were (620,700°C). These values were selected because using temperature higher than 700°C can cause higher porosity and using temperature lower than 620°C leads to solidifying the melt before the application of squeeze pressure. After that the squeeze pressure is applied for 30 seconds at a delay time of 5 seconds and allowing for solidification. The casting pressures that are used for all castings are (7.5, 23, 38, 53 MPa) according to what can be get from the squeeze press. Also it is chosen since it is not used before in the literature. The squeeze die is made of alloy steel and the dimensions of the resulted specimens are (100*15*30 mm). A (24) experiments were conducted at the mentioned parameters. The density is then calculated by taking the weight and volume of each specimen, and the castings are tested for hardness by Vickers method and wear rate by pin-on-disc apparatus. Table (2) shows the results of density, hardness and wear rate for all of the produced composites.

OPTIMIZATION OF SQUEEZE CASTING PROCESS PARAMETERS

The main theme of merit rating method is to reduce the variations in quality characteristics by selecting the best combination of process parameters that give the best results. All the elements must be normalized to the same units so that we can consider all the possible criteria in our decision problem. This method is efficient in combining the quality characteristics (i.e. larger the better, and smaller the better) in one parallel sequence manipulation in order to reach the best parameters.

In Y_2O_3/Al-Si composites, it was assumed that the wear rate have the most importance in the field of application, and the hardness come in the second importance sequence, while density come in the third. The importance of each property is shown in table (3).

The sequence of parameters optimization is as follows:

1. **Input Stage**

This stage contains the database of all used process parameters for each group, and the resulted values for each property. It must distinguish between the properties that must be as higher as possible which are density and hardness, and the properties that must be as lower as possible which is the wear rate. This database is shown in table (2).

2. **Calculating Weighting Factor (α)**

This stage consists of the following:

a. Calculating the number of possible decisions (N) from the following formula [Farag1979, Jahazi2004, Dehghan2007]:

$$N = n (n-1) / 2 \qquad (1)$$

Where: n: number of properties

b. Calculating the number of positive decisions (m).

A programmed mathematical approach by visual basic was previously constructed by the author and co-workers to calculate the number of possible decisions (N), and the number of positive decisions (m), (which is indicative of the importance of one property as compared to others), and is used here for the calculation of (m). The objective of creating (m) is to specify an importance of each property as required according to the involved application, and this importance is represented by numbers. The summation of (m) for all properties must be equal to (N). Figure (1) shows the form of the program.

c. Calculating of weighting factor (α) for each property by the formula [Farag1979, Jahazi2004, Dehghan2007]:

$$\alpha = m / N \qquad (2)$$

Summation of weighting factor for all properties must equal to unity. The values of n, N, m and α are shown in table (4).

3. **Calculating the Merit (M)**

For the properties that must be as high as possible, the larger value in each property for all groups of specimens must be replaced by 100 and then M can be calculated by the following [Farag1979, Jahazi2004, Dehghan2007]:

$$M = (\text{property value for each group of parameters / larger value})*100 \qquad (3)$$

For the properties that must be as low as possible, the smaller value in each property for all groups of specimens must be replaced by 100 and then M can be calculated by the following [Farag1979, Jahazi2004, Dehghan2007]:

$$M = (\text{lower value / property value for each group of parameters})*100 \qquad (4)$$

4. **Calculating Weighting Merit (WM)**

The Weighting Merit (WM) can be calculated for each property and group by the following formula [Farag1979, Jahazi2004, Dehghan2007]:

$$WM = M * \alpha \qquad (5)$$

5. **Calculating the Rating**

The rating can be calculated from the summation of all WM values for each group as follows [Farag1979, Jahazi2004, Dehghan2007]:

$$Rating = \Sigma WM \qquad (6)$$

Table (5) shows the values of M, WM and Rating.

RESULTS AND DISCUSSION

From the results of optimization for the process parameters affecting the production of Y_2O_3 reinforced Al-Si matrix composites shown in Table (5), it can be seen that group (8) which represents the composite produced at Tp = 700˚C, Td = 200˚C and P =

53 MPa had gave the higher rating and hence it have the first preference. This group is followed by group 12 and then group 7 in the preference results. Although group 7 have slightly lower wear rate (which is suggested to have the higher importance) than group 8, the method have chosen group 8 since it have the highest value in hardness when compared to the other groups (although it have lower importance sequence than the wear rate according to our suggestion). In other words, the difference in the hardness values between group (8) and group (7) or group (12) is bigger than the difference in wear rate and density among those groups and hence this higher difference has an influence and plays a major role in the selection process with the importance sequence. This was never mentioned before in the literature.

These results were compared with the results of squeeze cast graphite particles reinforced Al-Si composites that mentioned in reference [Osama2008], and showed a similarity in the parameters that gave the higher properties. This is an evidence of the success of merit rating method in finding the best balance of process parameters that give the best balance of the resulted properties.

CONCLUSIONS

This paper has reported an investigation in which merit rating method is applied to determine the optimal squeeze casting process parameters used in the preparation of Y_2O_3/Al–Si composites. For this purpose, concepts like weighting factor, merit, weighting merit and rating were employed. In light of our analysis the following conclusions were drawn:

1. The optimum level of process parameters to obtain high density and hardness and low wear rate are Tp = 700˚C, Td = 200˚C and P = 53 MPa. This is based on the results of merit rating method on the squeeze casting parameters that selected and used in this study.
2. The difference in property values among specimens can affect the selection process with the importance sequence if it is high (i.e. the higher the difference, the bigger the influence).
3. Merit rating method has proved its success in finding the optimum parameters to reach the good balance of the properties that are deferent and conflict.

Table 1 chemical composition (wt%) of the (Al-Si) alloy.

Si	Cu	Fe	Mn	Mg	Al
14	0.53	0.32	0.21	0.25	Balance

Table 2 database showing the values of properties for each group of parameters for the Y_2O_3/Al-Si composites.

Groups	Squeeze Casting Parameters [Tp(˚C),Td(˚C),P(MPa)]*	Wear Rate $*10^{-9}$ (cm^3/cm)	Hardness (VHN)	Density (gm/cm^3)
1	700, 300, 7.5	7.921	82	2.51
2	700, 300, 23	7.942	83	2.557
3	700, 300, 38	7.851	85	2.596
4	700, 300, 53	7.562	85	2.598
5	700, 200, 7.5	7.851	84	2.581
6	700, 200, 23	6.746	89	2.596
7	700, 200, 38	5.931	124	2.596
8	700, 200, 53	5.942	129	2.598
9	700, 100, 7.5	8.941	74	2.542
10	700, 100, 23	7.714	84	2.58
11	700, 100, 38	6.411	99	2.594
12	700, 100, 53	5.935	127	2.6
13	620, 300, 7.5	8.641	78	2.553
14	620, 300, 23	7.917	82	2.568
15	620, 300, 38	6.483	96	2.596
16	620, 300, 53	5.943	109	2.612
17	620, 200, 7.5	8.931	75	2.544
18	620, 200, 23	7.921	78	2.592
19	620, 200, 38	6.441	94	2.593
20	620, 200, 53	5.982	102	2.598
21	620, 100, 7.5	10.529	69	2.456
22	620, 100, 23	10.977	70	2.592
23	620, 100, 38	9.914	71	2.594
24	620, 100, 53	9.527	73	2.597

* Tp = Pouring Temperature, Td = Die temperature, P = Squeeze casting pressure

Table 3 database showing the importance sequence for each property.

Property	Importance
Wear Rate (cm^3/cm)	1
Hardness (VHN)	2
Density (gm/cm^3)	3

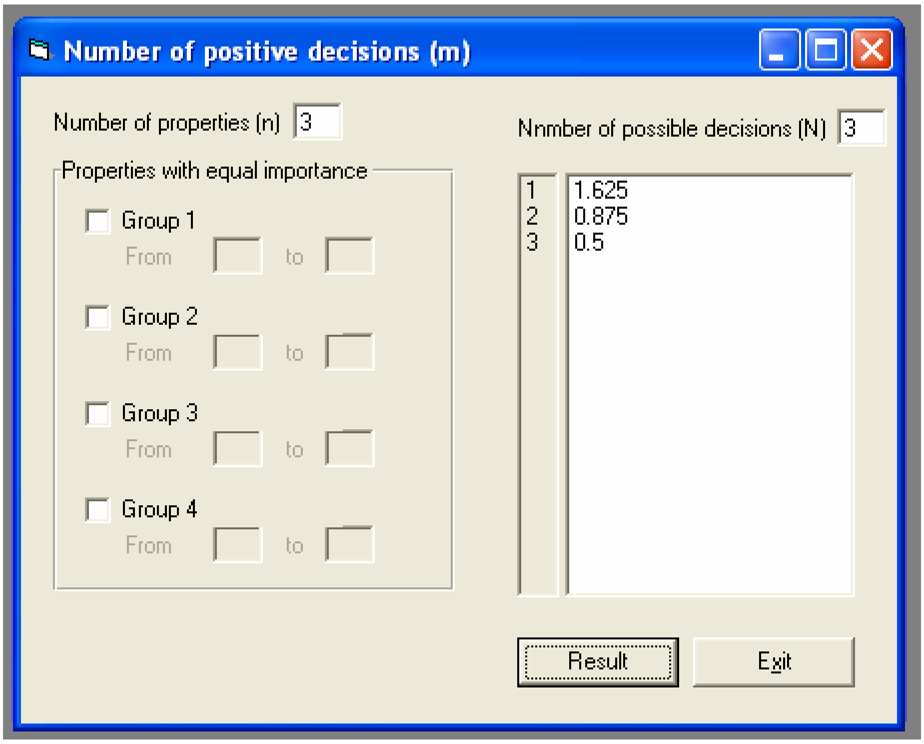

Fig. 1 the program that used to calculate the number of positive decisions for each property.

Table 4 shows the calculated values of the weighting factor for each property.

Properties	No. of Properties (n)	No. of Possible Decisions (N)	No. of Positive Decisions (m)	Weighting Factor (α)
Wear Rate	3	3	1.625	0.5417
Hardness			0.875	0.2917
Density			0.5	0.1666
			Σm = N	Σα = 1

Table 5 shows the calculated values of M, WM, and Rating for each group of squeeze casting parameters for the Y_2O_3/Al-Si composites.

Groups	Wear Rate		Hardness		Density		Rating	Pref.*
	M	WM	M	WM	M	WM		
1	74.877	40.561	63.566	18.542	96.095	16.009	75.112	16
2	74.679	40.454	64.341	18.768	97.894	16.309	75.531	14
3	75.545	40.923	65.891	19.22	99.387	16.558	76.701	12
4	78.432	42.487	65.891	19.22	99.464	16.571	78.278	10
5	75.545	40.923	65.116	18.994	98.813	16.462	76.379	13
6	87.919	47.626	68.992	20.125	99.387	16.558	84.309	9
7	100	54.17	96.124	28.039	99.387	16.558	98.767	3
8	99.815	54.07	100	29.17	99.464	16.571	99.811	1
9	66.335	35.934	57.364	16.733	97.32	16.214	68.881	20
10	76.886	41.65	65.116	18.994	98.775	16.456	77.1	11
11	92.513	50.114	76.744	22.386	99.311	16.545	89.045	6
12	99.933	54.134	98.45	28.718	99.541	16.584	99.436	2
13	68.638	37.181	60.465	17.638	97.741	16.284	71.103	18
14	74.915	40.581	63.566	18.542	98.315	16.379	75.502	15
15	91.485	49.557	74.419	21.708	99.387	16.558	87.823	7
16	99.798	54.061	84.496	24.647	100	16.66	95.368	4
17	66.409	35.974	58.14	16.959	97.397	16.226	69.159	19
18	74.877	40.561	60.465	17.638	99.234	16.532	74.731	17
19	92.082	49.881	72.868	21.256	99.273	16.539	87.676	8
20	99.147	53.708	79.07	23.065	99.464	16.571	93.344	5
21	56.33	30.514	53.488	15.602	94.028	15.665	61.781	23
22	54.031	29.269	54.264	15.829	99.234	16.532	61.63	24
23	59.824	32.407	55.039	16.055	99.311	16.545	65.007	22
24	62.255	33.724	56.589	16.507	99.426	16.564	66.795	21

*Preference

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