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Taguchi Based Gray Relational Analysis of Production Parameters of Al7075/B_4C/GNPs Hybrid Composites

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Anahtar Kelimeler

Hibrit Kompozit
Toz Metalurjisi
Grafen Nanoplatelet
Gri İlişkisel Analiz
Taguchi

Graphical/Tabular Abstract (Grafik Özet)

In this study, mixture powders prepared by adding Al7075 powders containing B_4C and GNPs in different weight ratios were compressed at room temperature and different pressing pressures and sintered at different temperatures in vacuum environment. Hardness and densification values were optimized with Taguchi-based gray relationship analysis. / Bu çalışmada farklı ağırlık oranlarında B_4C ve GNPs içeren Al7075 tozlarının eklenmesiyle hazırlanan karışım tozları oda sıcaklığında ve farklı presleme basınçlarında sıkıştırılmış ve farklı sıcaklıklarda vakum ortamında sinterlenmiştir. Taguchi tabanlı gri ilişki analizi ile sertlik ve yoğunlaşma değerleri optimize edilmiştir.

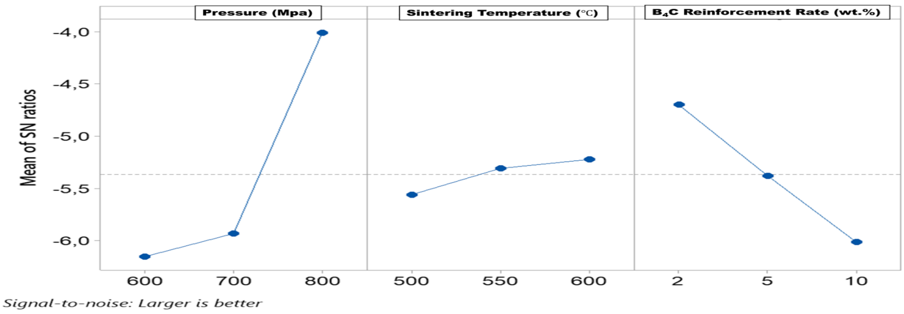

***Figure A:** S/N ratio for GRD / **Şekil A:** GRD için S/N oranları*

Highlights (Önemli noktalar)

- *Production of Al7075/B_4C/GNPs Hybrid Composites / Al7075/B_4C/GNPs hibrit kompozi üretimi*
- *Taguchi-based gray relationship analysis / Taguchi tabanlı gri ilşiki analizi*
- *Densification rate and hardness relationship / Yoğunlaşma oranı ve sertlik ilişkisi*

***Aim (Amaç):** Determination of the most optimum production conditions for hybrid composites produced by powder metallurgy method. / Toz metalurjisi yöntemiyle üretilen hibrit kompozitler için en uygun üretim koşullarının belirlenmesidir.*

***Originality (Özgünlük):** Al7075/B_4C/GNPs Hybrid Composites were produced by solid phase sintering method. / Al7075/B_4C/GNPs Hibrit Kompozitleri katı faz sinterleme yöntemiyle üretildi.*

***Results (Bulgular):** According to the Taguchi-based gray relational analysis methodology, the best parameter was determined as 700 MPa pressure. 600 °C sintering temperature and 2% B4C reinforcement rate (A3-B3-C1). / Taguchi tabanlı gri ilişkisel analiz metodolojisine göre en iyi parametre 700 MPa basınç olarak belirlendi. 600 °C sinterleme sıcaklığı ve %2 B4C takviye oranı (A3-B3-C1).*

***Conclusion (Sonuç):** It has been determined that the sintering temperature is the main variable for hybrid composites produced by the solid-solid production technique in powder metallurgy. / Toz metalurjisinde katı-katı üretim tekniği ile üretilen hibrit kompozitler için sinterleme sıcaklığının ana değişken olduğu belirlenmiştir.*

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Abstract

In this study, metal matrix hybrid composites obtained by adding B_4C and graphene nanoplatelets (GNPs) powders as reinforcement elements to Al7075 powders were produced by powder metallurgy (P/M) method. Mixture powders prepared by supplementing Al7075 powders with different weight ratios of B4C (2-5-10%) and GNPs (0.5%) are compressed at room temperature and at different pressing pressures (600-700-800 MPa) and then at different temperatures (500-550- 600°C) was sintered in vacuum atmosphere and samples were produced in accordance with ASTM G99 standard. Density and hardness analyzes were carried out depending on the changing production parameters of hybrid composites. It was determined that the pressing pressure had a direct effect on the condensation rate of the samples and the highest density value was 2.6764 g/cm^3 in the Al7075+5% B_4C+0.5% GNPs sample pressed under 800MPa pressure. The hardness of the samples, on the other hand, generally increased due to the increasing amount of reinforcement element, while it also increased with the increase of pressing pressure and sintering temperature.

Al7075/B4C/GNP's Hibrit Kompozitlerin Üretim Parametrelerinin Taguchi Tabanlı Gri İlişkisel Analizi

Makale Bilgisi

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Öz

Bu çalışmada, Al7075 tozlarına takviye elemanı olarak B_4C ve grafen nanoplatelet (GNPs) tozlarının eklenmesiyle elde edilen metal matrisli hibrit kompozitler, toz metalurjisi (T/M) yöntemiyle üretildi. Farklı ağırlık oranlarında B_4C (%2-5-10) ve GNPs (%0,5) içeren Al7075 tozlarının eklenmesiyle hazırlanan karışım tozlar, oda sıcaklığında ve farklı presleme basınçlarında (600-700-800 MPa) ve ardından farklı sıcaklıklarda sıkıştırılır. (500-550- 600°C) vakum ortamında sinterlenerek ASTM G99 standardına uygun numuneler üretilmiştir. Hibrit kompozitlerin değişen üretim parametrelerine bağlı olarak yoğunluk ve sertlik analizleri yapılmıştır. Presleme basıncının numunelerin yoğuşma oranına doğrudan etki ettiği ve en yüksek yoğunluk değerinin 800MPa basınç altında preslenen Al7075+%5 B_4C+%0,5 GNPs numunesinde 2,6764 g/cm^3 olduğu belirlendi. Numunelerin sertliği ise takviye elemanı miktarının artmasına bağlı olarak genel olarak artarken, presleme basıncı ve sinterleme sıcaklığının artmasıyla da artış göstermiştir.

1. INTRODUCTION (GİRİŞ)

Aluminum alloys are widely used in various industries due to their low density, energy efficiency in manufacturability and superior mechanical-corrosive properties[1]. Since the first development of Al 7075 alloys in the 1960s, it has been an important and indispensable material in the aviation industry, especially for the manufacture of aircraft wing pylons, airframes and rockets. It has a very common use in the automotive industry due to its low density and superior specific strength values[2-3]. Aluminum alloys are a separate phenomenon in the industry, as research has proven that reducing the weight of a vehicle by 10% reduces fuel consumption by 1.9–8.2%, depending on the vehicle's driving style, size and model[4]. Despite the wide range of applications, aluminum alloys require even higher strength to meet the specific requirements of industrial applications. Expected mechanical strengths can be gained by applying secondary processes such as heat treatment,

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thermomechanical and thermochemical treatment [5-7]. GNPs are considered as highly effective reinforcing fillers in metal matrix composites such as aluminum, iron, titanium [8-10]. Optimization of experimental parameters is the main phenomenon to obtain a better response as well as to save labor, time, materials and money in the experimental work. [11-12]. In recent years, many modeling and optimization tools such as artificial neural networks and response surface methodology have been used in many multidisciplinary studies by various researchers [13-15].

2. MATERIALS AND METHODS (MATERYAL VE METOD)

2.1. Experimental Equipment (Deneysel Ekipman)

In the experimental studies, spherical shaped Al7075 powders (Nanography) with 99.5% purity and an average particle size of <44 µm produced by water atomization technique were used. Al7075 matrix is composed of B4C powders (Nanography) of 99.95% purity, with different reinforcement ratios (2-5-10%) by weight and an average grain size of 44 µm, with a single layer, average powder size D50= 3nm, 800 m²/g surface area and high GNPs powders (Nanography) of purity (99.99%) were added at 0.5% by weight. In order to obtain a homogeneous distribution, the prepared powders were mixed with a 3D Turbola TF2 mixer for 2 hours. The resulting mixture powders were shaped in accordance with ASTM G-99 standards under varying pressure (600-700-800MPa) with the help of a hydraulic press at room temperature. All samples were sintered at different temperatures (500-550-600°C) for 30 minutes in a vacuum atmosphere of 5x10-2 Pa. The densities of hybrid composite (HC) samples with different production parameters and chemical compositions after pressing and sintering were determined according to ASTM B962-17 standard using an electronic density meter (A&D HR-250AZ) according to Archimedes principle. Conventional metallography processes were applied to all samples to reveal the microstructures and etched with Keller's solution (95% H2O, 1.5% HCl, 1% HF and 2.5% HNO3). HV0.5 microhardness measurements of the samples according to ASTM E384 were made with a Qness 60 M EVO tester using a diamond tip under 0.5 kg (4.9N) load. Taguchi-based gray relational analysis methodology was successfully applied for HV. d and P simultaneously in the multi-response optimization process. Accordingly. the best parameters were determined as 700 MPa pressure. 600 ℃ sintering temperature and 2% B4C reinforcement ratio (A3-B3-C1).

2.2 Taguchi-Based Gray Relational Analysis (GRA) (Taguchi Tabanlı Gri İlişkisel Analizi)

In recent years, Tagichi-based gray relational analysis (GIA) has been widely used to optimize parameters according to multiple outputs. At the same time, the processing outputs (responses) have different units of measurement as they are obtained using different devices. In this respect, the first operation of GIA is to accept each of these outputs as a factor and convert them to the same unit. First, experimental results are normalized to reduce variability. In other words, this procedure is a means of transferring the original sequence to a comparable sequence, thus normalizing experimental results ranging from 0 to 1. Normalization of test results can be done with the following three different approaches [16-18].

If "bigger is better", the results are normalized to the following equation:

$$x_i(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \quad (1)$$

If "smaller is better," the results are normalized to the following equation:

$$x_i(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - min\, x_i^0(k)} \quad (2)$$

If "nominal is better", the results are normalized to the following equation:

$$x_i(k) = 1 - \frac{|x_i^0(k) - x^0|}{\max x_i^0(k) - x^0} \quad (3)$$

Then, the gray relational coefficient (GRC) is calculated based on the normalized test results to define the relationship between the expected and actual experimental values. GRC can be found using the following equation:

$$\xi_i(k) = \frac{\Delta_{min} + \varsigma\Delta_{max}}{\Delta_{0i}(k) + \varsigma\Delta_{max}} \quad (4)$$

Then, using the GRCs, its value is found as a relational degree of gray (GRD). GRD is found using the following equation:

$$\Upsilon_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad (5)$$

In the last step of the Gray Relational Analysis based on the Taguchi method, the optimum levels of the parameters are found by considering the S/N ratio for GRA. Therefore, since a higher VAR is targeted, the "bigger is better" case is used to obtain the best parameters for multi-response optimization [17,19]. For a higher GRA, the signal-to-noise (S/N) values are obtained using the following equation:

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (6)$$

Finally, validation experiments are performed at optimal process parameters to confirm the multiple response optimization. Therefore, the estimated GRD at optimal parameters is defined by the following equation:

$$\eta_{predicted} = \eta_m + \sum_{i=1}^{n}(\eta_i - \eta_m) \quad (7)$$

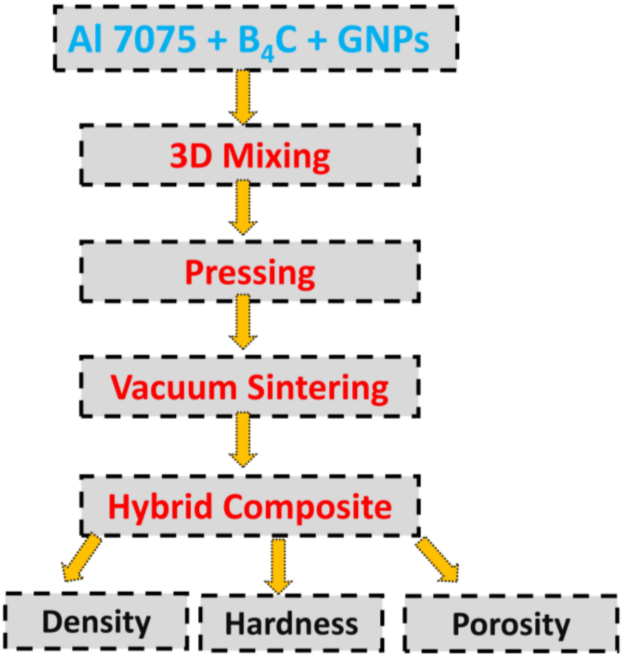

Figure 1. Experimental studies flow chart (Deneysel çalışmalar akış şeması)

3. RESULTS (BULGULAR)

The % porosity values of the samples after sintering were calculated using equation (1). It was determined that the porosity of the samples decreased and their density increased depending on the increasing pressing pressure and presented in Table 1.

$$\boldsymbol{Porosity}(\%) = \frac{\boldsymbol{Theoretical\ Density - Sintering\ Density}}{\boldsymbol{Theoretical\ Density}} \times \mathbf{100}$$

(1)

Table 1. Hardness-density values of HC samples produced in different variables (Farklı değişkenlerde üretilen HC numunelerinin sertlik-yoğunluk değerleri)

Test Sample			**Experimental Measurements**		
Pressing Pressure **(MPa)**	Sintering Temperature **(°C)**	B_4C Reinforcement Ratio **(%)**	Hardness **(HV0.5)**	Density **(g.cm^{-3})**	Pore Ratio (%) **(%)**
600	500	2	73	2.5291	9.67
600	550	5	71	2.6079	6.86
600	600	10	69	2.6278	6.15
700	500	5	74	2.5793	7.88
700	550	10	79	2.6081	6.85
700	600	2	75	2.6439	5.57
800	500	10	79	2.5917	7.43
800	550	2	85	2.6181	6.49
800	600	5	83	2.6764	4.41

3.1. Multiple Optimization (Çoklu Optimizasyon)

In the second stage of this study, the mixture powders prepared by supplementing Al7075 powders with different weight ratios of B4C (2-5-10%) and GNPs (0.5%) were compressed at room temperature and at different pressing pressures (600-700-800 MPa) and then at different temperatures. (500-550-600°C) vacuum atmosphere and optimized according to the results of hardness, density and pore ratio for samples conforming to ASTM G99 standard.

Table 2. Gray relational analysis results (Gri ilişkisel analiz sonuçları)

Experiment no	Experiment results			Normalized values			Coefficients					
	HV	D	P	HV	D	P	HV	D	P	GRD	S/N	Serie
1	73	2.5291	9.6750	0.250	1.000	0.000	0.400	1.000	0.333	0.578	-4.76478	3
2	71	2.6079	6.8607	0.125	0.465	0.535	0.364	0.483	0.518	0.455	-6.84066	8
3	69	2.6278	6.1500	0.000	0.330	0.670	0.333	0.427	0.602	0.454	-6.85177	9
4	74	2.5793	7.8821	0.313	0.659	0.341	0.421	0.595	0.431	0.482	-6.33272	7
5	79	2.6081	6.8536	0.625	0.464	0.536	0.571	0.482	0.519	0.524	-5.60923	5
6	75	2.6439	5.5750	0.375	0.221	0.779	0.444	0.391	0.694	0.510	-5.85374	6
7	79	2.5917	7.4393	0.625	0.575	0.425	0.571	0.541	0.465	0.526	-5.58531	4
8	85	2.6181	6.4964	1.000	0.396	0.604	1.000	0.453	0.558	0.670	-3.47428	2
9	83	2.6764	4.4143	0.875	0.000	1.000	0.800	0.333	1.000	0.711	-2.96125	1

For this reason. Taguchi-based gray relational analysis methodology was used to improve and optimize the parameters affecting the results. In the current study. a "bigger is better" approach to simultaneously increase HV and a "smaller is better" approach to minimize d and P was applied in the multi-response optimization process [19]. First. the experimental results are normalized using equation 2. Equations 4 and 5 were used for GRC and GRG values. respectively. In addition. the S/N values of the multiple response were obtained by equation 6. The values obtained as a result of the experiments and calculations are given in Table 4.

In this table. the high GID value indicates the optimum level. with a strong relationship between the experimental results and the normalized values. Also. the response table for GRD is given in Table 3. The maximum value corresponding to each parameter in this table represents the optimum level. From now on. the optimal parameter level can be determined using Figure 2 and/or the response table. Accordingly. the best combination parameters are; 700 MPa pressure. 600 °C sintering temperature and 2% B4C reinforcement ratio (A3-B3-C1).

Table 3. Response table for GRD (GRD için yanıt tablosu)

Parameters	Level 1	Level 2	Level 3	Difference
Pressure. MPa	0.496	0.505	**0.636**	0.140
Sintering Temperature. °C	0.529	0.550	**0.558**	0.030
B_4C reinforcement ratio. %	**0.586**	0.549	0.501	0.084

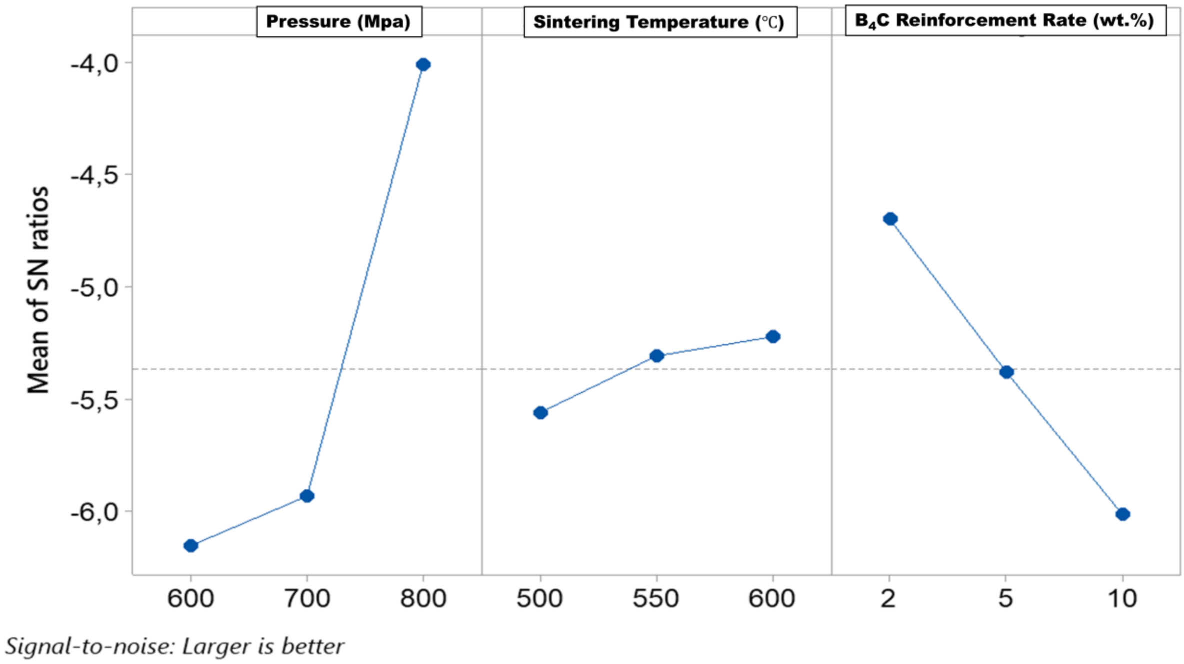

Figure 2. S/N ratio for GRD (GRD için S/N oranı)

3.2. Verification of Optimization (Optimizasyon Doğrulaması)

The last step in Taguchi-based gray relational analysis is the verification of the determined optimum parameter. For this purpose. the GRD (η_predicted) estimation process was obtained using equation 7 with a confidence level of 0.05. Confirmation experiments were performed three times using the determined optimum parameters. After taking the average of the test results. the HV , d and P values obtained as 81 hardness. 2.6465 g.cm^{-3} density and 3.3245% porosity. respectively. are given in Table 4.

Table 4. Confirmation experiment results (Doğrulama deneyi sonuçları)

	Initial parameter	Optimal parameter	
		Estimated	Experimental
Level	A2-B2-C2	A3-B3-C1	A3-B3-C1
HV	75		81
d (g.cm^{-3})	2.5976		2.6465
P (%)	7.2541		3.3245
GRG	0.481	0.6888	0.920
amount of recovery = 0.439			

When the results are evaluated. it is seen that the estimated results are better. It was observed that there was a good correlation between the estimated GRD and the experimental GRD results. In the light of the results. the amount of improvement in GRD from the initial parameters to the optimum parameters was 0.439. The values obtained from the validation test showed that the GRG values were consistent with the confidence interval limits. In conclusion. Taguchi-based gray relational analysis methodology has been successfully applied for HV. d. and P.

4. CONCLUSIONS (SONUÇLAR)

In this study. the mixture powders prepared by supplementing Al7075 powders with different weight ratios of B4C (2-5-10%) and GNPs (0.5%) were compressed at room temperature and different pressing pressures (600-700-800 MPa) and then at different temperatures (500 MPa). -550-600℃) was sintered in vacuum atmosphere and optimized according to the results of hardness. density and pore ratio for samples conforming to ASTM G99 standard.

The summarized results are given below:

• The highest hardness value was measured as 85 HV in the sample containing 2% B4C at 800 MPa compression pressure at 550°C.

• Taguchi-based gray relational analysis methodology was successfully applied for HV. d and P simultaneously in the multi-response optimization process. Accordingly. the best parameters were determined as 700 MPa pressure. 600 ℃ sintering temperature and 2% B4C reinforcement ratio (A3-B3-C1).

• As a result of validation experiments with optimum parameters. an improvement of 0.439 was obtained.

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Onur ALTUNTAŞ*:** He conducted the experiments, analyzed the results and performed the writing process.

Deneyleri yapmış, sonuçlarını analiz etmiş ve maklenin yazım işlemini gerçekleştirmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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