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The Effect of High Pressure Die-Casting Machine's Parameters on the Mechanical Properties of the Aluminium Alloy Material

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Anahtar Kelimeler

Alüminyum
Yüksek Basınçlı Döküm
Faktöriyel tasarım
Mekanik Özellikler
Deney Tasarımı
Varyans Analizi

Graphical/Tabular Abstract (Grafik Özet)

In the study, firstly, the part and raw material to be tested were determined, then the injection production parameters were determined and production was made, and at the end, the data were analyzed with statistical analysis. / Çalışmada ilk olarak deney yapılacak parça ve hammadde belirlenmiş, daha sonra enjeksiyon üretime parametreleri belirlenerek üretim yapılmış ve sonunda ise istatiksel analiz ile veriler analiz edilmiştir.

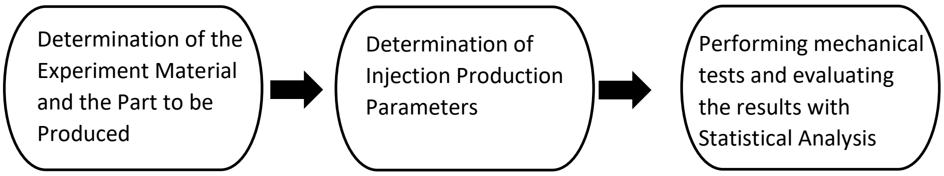

***Figure A**: WorkFlow / **Şekil A**:.Çalışma Akışı*

Highlights (Önemli noktalar)

- *Aluminium injection / Alüminyum enjeksiyon*
- *Full factorial design of experiment / Tam faktöriyel deney tasarımı*
- *Interpretation of experiment data with statistical analysis / İstatiksel analiz ile deney verilerinin yorumlanması*

Aim (Amaç): *In this study, it is aimed to see the effect of aluminum injection parameters on the mechanical properties of the material used. / Çalışmada alüminyum enjeksiyon parametrelerinin kullanılan malzemenin mekanik özelliklerine etkisinin görülmesi amaçlanmıştır.*

Originality (Özgünlük): *While determining the injection parameters in the study, the full factorial experimental design method was used, and the obtained values were evaluated by analysis of variance. / Çalışmada enjeksiyon parametreleri belirlenirken tam faktöriyel deney tasarımı yöntemi kullanılmış ve elde edilen değerler varyans analizi ile değerlendirilmiştir.*

Results (Bulgular): *According to the main effects graph, when the molten metal temperature is 725 ℃, the injection speed is 4.0 m/s, and the mold opening time is 10 s, the best hardness value is obtained, the molten metal temperature is 725 ℃, the injection speed is 2.6 m/s, and the mold opening time is 15 s. the best tensile strength was obtained. / Ana etkiler grafiğine göre ergimiş metal sıcaklığı 725 ℃, enjeksiyon hızı 4,0 m/s ve kalıp açma süresi 10 s olduğunda en iyi sertlik değerinin, ergimiş metal sıcaklığı 725 ℃, enjeksiyon hızı 2,6 m/s ve kalıp açma süresi 15 s olduğunda ise en iyi çekme dayanımı elde edilmiştir.*

Conclusion (Sonuç): *As a result of the statistical analyzes, it was seen that the molten metal temperature (725 ℃) was the parameter that most affected both hardness and tensile strength. /Yapılan istatiksel analizler sonucunda, ergimiş metal sıcaklığının (725 ℃) hem sertlik hem de çekme dayanımını en çok etkileyen parametre olduğu görülmüştür.*

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The Effect of High Pressure Die-Casting Machine's Parameters on the Mechanical Properties of the Aluminium Alloy Material

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Abstract

Aluminium is one of the fundamental materials used in many sectors, such as, automotive, defence, aviation, etc. Generally, aluminium parts are formed by using die-casting methods in manufacturing industry. Machines, which are used, for die-casting process have many parameters that affect the molded parts' mechanical properties. In this study, the effect of casting parameters on the mechanical properties of used material was investigated. A test part that is manufactured currently on a die-casting machine in a sector was found out to do experimental works. An aluminum alloy, named Al$Si_{12}Cu$ (EN AC 47000), that is used widely in die-casting techniques was preferred. Three parameters, such as, metal injection velocity (m/s), time of the die opening (s) and molten metal temperature (℃), were selected. In addition, 27 test parts that were determined by the full factorial experimental design method were manufactured for the molding parameters. Moreover, some mechanical tests, hardness and tensile, were performed on the parts. The test data were analysed with the full factorial and ANOVA statistical methods. As a results of the analysis, the highest hardness value was obtained as 85 HB when the molten metal temperature was 750 °C, the injection velocity was 1,3 m/s and the mold opening time was 10 s. The maximum value of the tensile strength was gotten as 264 MPa in the parameters that are the molten metal temperature 725 °C, injection velocity 4 m/s and the mold opening time was 12 s.

Yüksek Basınçlı Döküm Makinesi Parametrelerinin Alüminyum Alaşımlı Malzemenin Mekanik Özelliklerine Etkisi.

Makale Bilgisi

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Öz

Alüminyum, otomotiv, savunma, havacılık vb. birçok sektörde kullanılan temel malzemelerden biridir. İmalat sanayinde genellikle basınçlı döküm yöntemleri kullanılarak alüminyum parçalar oluşturulmaktadır. Basınçlı döküm işleminde kullanılan makineler, kalıplanan parçaların mekanik özelliklerini etkileyen birçok parametreye sahiptir. Bu çalışmada döküm parametrelerinin kullanılan malzemenin mekanik özelliklerine etkisi incelenmiştir. Halihazırda bir sektörde basınçlı döküm makinesinde imal edilen bir test parçasına deneysel çalışmalar yapılmıştır. Basınçlı döküm tekniklerinde yaygın olarak kullanılan AlSi_{12}Cu\ (EN AC 47000) adlı alüminyum alaşımı tercih edilmiştir. Metal enjeksiyon hızı (m/s), kalıp açma süresi (s) ve ergimiş metal sıcaklığı (℃) gibi üç parametre seçilmiştir. Ayrıca kalıplama parametreleri için tam faktöriyel deneysel tasarım yöntemi ile belirlenen 27 adet test parçası üretilmiştir. Ayrıca parçalar üzerinde sertlik ve çekme gibi bazı mekanik testler yapılmıştır. Test verileri tam faktöriyel ve ANOVA istatistiksel yöntemleri ile analiz edildi. Analiz sonucunda ergimiş metal sıcaklığı 750 °C, enjeksiyon hızı 1,3 m/s ve kalıp açma süresi 10 s olduğunda en yüksek sertlik değeri 85 HB olarak elde edilmiştir. Erimiş metal sıcaklığı 725 °C, enjeksiyon hızı 4 m/s ve kalıp açma süresi 12 s olan parametrelerde çekme dayanımının maksimum değeri 264 MPa olarak elde edilmiştir.

1. INTRODUCTION (GİRİŞ)

Aluminium that is one of the main materials is preferred in many industries because of that it is abundant in nature, cheap and soft, as well as cost effective price. There are many methods, such as extrusion, rolling and casting, etc. to form aluminium alloy materials Especially, aluminium injection method is preferred in high volume production sectors such as automotive and defence industries [1]. As it is possible to manufacture complex-shape and thin-section parts by the high-

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pressure casting method. The aluminium injection method is also known die casting process. In this technique, the desired parts can be manufactured in high quantity and the closest to the final product by injecting molten metal into the metal mold at high pressure [2]. Normally, aluminium has low strength and soft when it is pure state. For this reason, different types of aluminium alloys are formed by adding some elements into it to improve strength, resistance and castability properties. The basic elements for aluminum alloys are Zn, Cu, Mn, Mg, Si and Fe. These elements affect strength and other mechanical, metallurgical properties of the formed alloy [1]. There are two main factors that greatly affect the quality of the molded parts [3]. One of them is distribution rate of the molten metal in the die and the other is the temperature of the mold. Moreover, there are three phases in the high-pressure casting process. In the first phase, the molten metal is slowly transmitted to the sprue inlet of the mold, and in the second phase, the molten metal is injected into the die under high pressure. In the third phase, the solidification process of the molten metal is completed by high pressure.

The high-pressure die-casting machines are divided into two as cold and hot chamber machines according to the different production systems. The chamber is where the molten metal is injected into the mold by means of pistons in the die-cast machine [4]. In cold chamber pressure casting machines, molten metal is filled into the chamber with a ladle. In hot chamber die casting machines, the molten metal furnace is located inside the machine [5].

In this study, the effect of the injection production parameters of the EN AC 47000 (AlSI $Si_{12}(Cu)$) which is used in aluminium injection machines on the mechanical properties of the material was investigated.

2. MATERIALS AND METHODS (MATERYAL VE METOD)

In this study, mechanical tests were carried out on the aluminum parts molded in the parameters determined in the high pressure die casting machine. Experimental results were analyzed using full factorial design and ANOVA methods.

2.1. Test Parts (Test Parçaları)

Aluminium alloy that is coded EN AC 47000 were selected a raw material that is called ingot for casting process on metal injection molding machine. Hardness values of the ingot were measured before melting. Hardness values were measured between 60 and 70 HB. EN AC 47000 aluminium alloy, which chemical content is specified in Table 1. The geometry of test parts were determined according to the mechanical tests, such as tensile. The tensile test specimens were cut out the parts.

Table 1. EN AC 47000 Aluminium alloy chemical content (EN AC 4700 Kimyasal içerik)

Al	Fe	Si	Cu	Mn	Mg	Zn	Ni	Ti	Pb	Sn
Remain	1,00	11,50-13,50	0,20	0,30	0,20	0,10	0,10	0,15	0,10	0,05

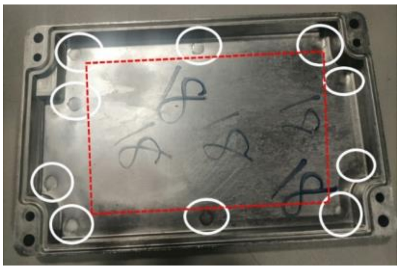
In the die-casting process, the molten metal temperature, injection speed and mold opening time were determined as injection parameters by taking into account the literature review [6] [3] [7]. The selected parameters are shown in Table 2.

Table 2. Injection production parameters (Enjeksiyon üretim parametreleri)

Factors	Level 1	Level 2	Level 3
Injection Velocity (m/s)	1,3	2,6	4
Mold Opening Time(s)	10	12	15
Molten Metal Temperature (℃)	700	725	750

According to the defined injection parameters, normally 27 (3*3*3) test parts have to need in this works. However, 54 (27*2) test parts were molded because of some problems that can be occurred in this experimental works. The cold chamber die-casting machine, which is seen in Figure 1-a, was used to manufacture all test samples. The mold temperature was kept constant during the pressing of the test samples. When the parts were removed from the die, they were left to cool at room temperature.

a)



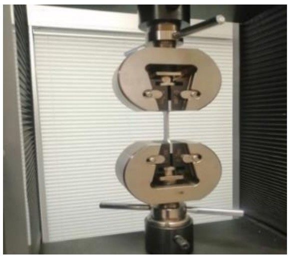
b)

Figure 1. High pressure die-casting machine (a) and molded part (b) (Yüksek basınçlı döküm makinesi ve kalıplanan parça)

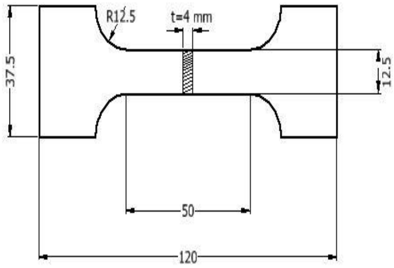
The dimensions of the test parts are 260x160x20 mm. While performing the mechanical tests, the specimens were cut out from a detected area on the parts. Where the traces of the ejector pin used to remove the part from the mold in the injection process, these regions are shown with a red dashed line in Figure 1-b, the area of the region is 160 x115 mm, and the thickness is 4 mm.

2.2. Mechanical Tests (Mekanik Testler)

According to the TS EN ISO 6892-1 standard, the tensile specimens were extracted from the test parts by using a CNC vertical machining tool. All the tensile tests were carried out at room temperature, at a tensile speed of 1 mm/min with a MITECH brand tensile device. Figure 2-a shows the test sample connected on the tensile device.



a)



b)

c)

Figure 2. Tensile testing device and specimen: a) Tensile device b) Technical drawing of test dpecimen, c) Cutting the test specimen out the molded part (Çekme testi cihazı ve numune: a)Çekme cihazı, b) Çekme numunesi teknik resmi, c) Çekme numunesinin kalıplanan parçadan çıkarılması)

The hardness tests were carried out for the test specimens. The measurement hardness was performed by using Brinell method. The molded parts' hardness was measured with a device in two times. As the hardness of the material was controlled for three different regions on the molded part (marked with circles in Figure 3), the average values were calculated for these tests' values.

Figure 3. Hardness test areas (Sertlik testi bölgeleri)

2.3. Factorial Method (Faktöriyel Metod)

The factorial experimental design method is an effective technique for estimating the main effects on the test results. In addition, the application of this method is quite easy in experimental works that need optimization [9]. In the full factorial experiment design method, the experiment costs and experiment times increase as the combinations of all the levels of the factors are tried one by one.To summarize briefly, there is maximum time and cost in full factorial experimental design. While designing the experiment, the connection between the data to be obtained from the experiment and the cost and time spent should be analyzed very well. In order to save cost and time, the fractional factorial experiment design method is obtained by proportionally reducing the number of experiments [14]. The most important feature of the full factorial design is that it examines the effect of the interaction of factors on the output [10]. It is seen that some methods, for example the variance (ANOVA) and regression analysis, are also used together with full factorial design. The variance analysis is used to determine the degree of impact of factors on output, and regression analysis is used to determine the mathematical relationship of inputs and output data [11]. Other useful exploratory analysis tools for factorial experiments include main effects plots, interaction plots, Pareto plots, and a normal probability plot of the estimated effects. Thus, the full factorial experimental design method was preferred in this study.

3. RESULTS AND DISCUSSION (SONUÇLAR VE TARTIŞMA)

In this section, the relation of the parameters, used on injection press machine, with the mechanical tests' results, hardness and tensile, was figured out. The experiments were organized by using full factorial method. (3^3x2) 54 different experiments are required since it is desired to examine 3 different factors with 3 levels and 2 repetitions. The purpose of performing the experiments in duplicate is to minimize the effect of uncontrollable external factors on the input parameters with the full factorial experimental design. Full factorial experimental design is shown in Table 3. After tests, the values of the hardness and the tensile tests were analysed with tools in full factorial experimental design.

Table 3. Full factorial experimental design (Tam faktöriyel deney tasarımı)

Specimen	Molten Metal Temperature (°C)	Injection Velocity(m/s)	Mold Opening Time (s)
1	700	4	10
2	700	4	12
3	700	4	15
4	700	2,6	10
5	700	2,6	12
6	700	2,6	15
7	700	1,3	10
8	700	1,3	12
9	700	1,3	15
10	725	4	10
11	725	4	12
12	725	4	15
13	725	2,6	10
14	725	2,6	12
15	725	2,6	15
16	725	1,3	10
17	725	1,3	12
18	725	1,3	15
19	750	4	10
20	750	4	12
21	750	4	15
22	750	2,6	10
23	750	2,6	12
24	750	2,6	15
25	750	1,3	10
26	750	1,3	12
27	750	1,3	15
28	700	4	10
29	700	4	12
30	700	4	15
31	700	2,6	10
32	700	2,6	12
33	700	2,6	15
34	700	1,3	10
35	700	1,3	12
36	700	1,3	15
37	725	4	10
38	725	4	12
39	725	4	15
40	725	2,6	10
41	725	2,6	12
42	725	2,6	15
43	725	1,3	10
44	725	1,3	12
45	725	1,3	15
46	750	4	10
47	750	4	12
48	750	4	15
49	750	2,6	10
50	750	2,6	12
51	750	2,6	15
52	750	1,3	10
53	750	1,3	12
54	750	1,3	15

3.1. Hardness Tests (Sertlik Testi)

The results of the hardness tests were analysed by using the method of full factorial experiment design. The purpose of analysis with factorial experimental design is to determine the impact of factors on the response variable interactively.

Table 4. Analysis of variance (Varyans analizi)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	26	1052,55	40,483	6,46	0,000
Linear	6	671,65	111,942	17,85	0,000
Temp	2	474,94	237,470	37,87	0,000
Velocity	2	29,19	14,594	2,33	0,117
Time	2	167,52	83,760	13,36	0,000
2-Way Interactions	12	290,91	24,242	3,87	0,002
Temp*Velocity	4	106,05	26,512	4,23	0,009
Temp*Time	4	75,11	18,776	2,99	0,036
Velocity*Time	4	109,75	27,439	4,38	0,007
3-Way Interactions	8	89,99	11,248	1,79	0,122
Temp*Velocity*Time	8	89,99	11,248	1,79	0,122
Error	27	169,32	6,271		
Total	53	1221,86			

The variance analysis results are given in Table 4. Each Factors affecting the hardness values were evaluated according to the *P* value that significance level was taken into account 5% (α=0.05). It is seen that the factors whose *P* value is below the significance level and the binary interactions affect the hardness value statistically. According to *P* values, the temperature, the time, velocity*time, temperature*velocity, temperature*time factors and interactions affect the hardness of the material. According to the sum of squares values, the factors and their effects are shown in Table 5.

Table 5. Hardness values sum of squares ratio (Sertlik testi kareler toplamı oranı)

Temperature	38,87%
Velocity	2,37%
Time	13,71%
Temperature*Velocity	8,67%
Temperature*Time	6,14%
Velocity*Time	8,98%
Temperature*Velocity*Time	7,36%

It is seen in Figure 4 that the factors and interactions that exceed the threshold value (2,052) in the Pareto chart affect the response variable. Temperature is the most important factor affecting the response variable according to the Pareto graph. This result was reached because the standardized effect value in the graph was at the highest temperature factor. After determining the degrees of freedom of the factors, the t table is checked for the threshold value. Standardized effects are t statistics that test the zero hypothesis that the effect is zero. The zero hypothesis is an assumption used in statistics that suggests that there is no difference between certain features of the data generation process. [12] The threshold value in the Pareto chart is calculated automatically by the statistical analysis program (Figure 6). To summarize, it is seen in the Pareto chart that the factors exceeding the threshold value and the interactions of the factors have an effect on the output.

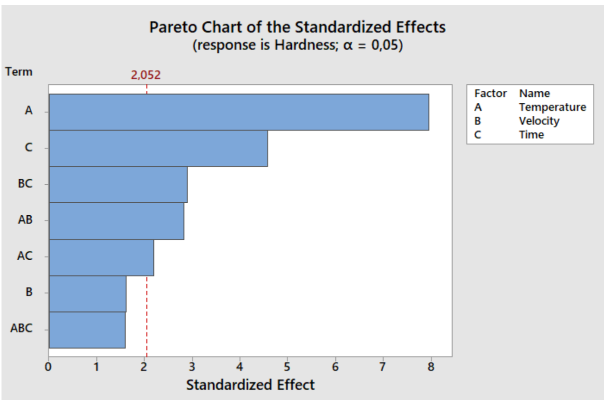


Figure 4. Pareto chart for hardness values (Sertlik testi pareto grafiği)

When the experimental design model was examined, it was seen that the R-sq value was 86,14% and the R-sq (adj) value was 72,80%. The high R-sq value indicates that the obtained data explains the experimental design model. The main effects graph is used to obtain information about the single effects of each factor on the output.[15] The main effects plot shown in Figure 5 has been reviewed to determine factors that have an effect on hardness value. According to the graph, the highest hardness values were obtained when the molten metal temperature was 725 °C, the velocity of injection was 4 m/s, and the mold opening time was 10 s.

In addition, the 3D graphics shown in Figure 6 have been drawn to visualize and better understand the effect of molding factors on the output. Each of these graphs shows the effect of 2 different input parameters on the output. It is seen that the temperature of the material, 725, is the most effective parameter in the 3D plots.

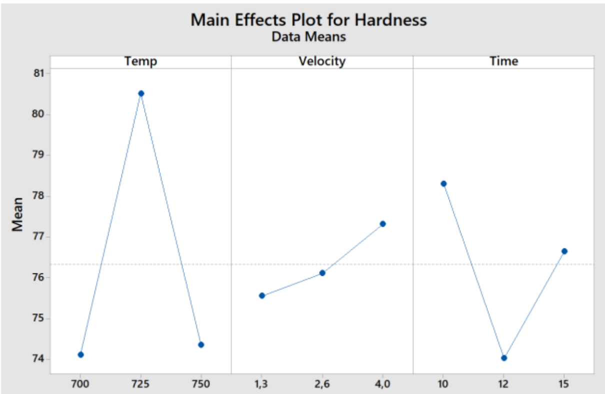
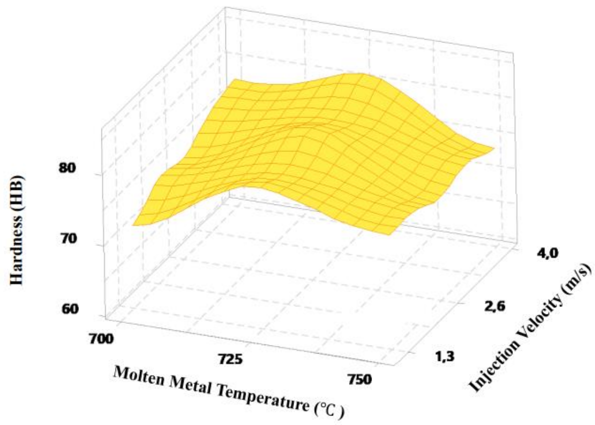
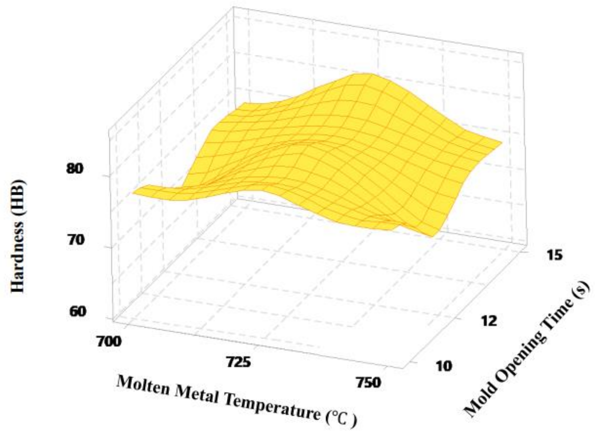


Figure 5. Main effects plot for hardness test (Sertlik testi ana etkiler grafiği)





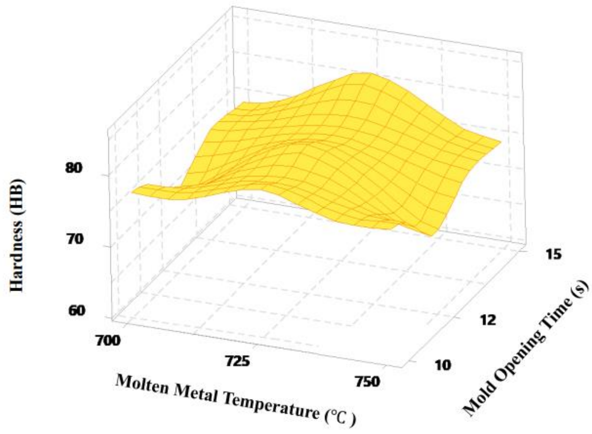


Figure 6. 3D Interaction plots for hardness test (Sertlik testi 3D etkileşim grafikleri)

3.2. Tensile Test (Çekme Testi)

Two tensile specimens were extracted from each test parts formed according to 27 different injection parameters. So, that means, the tensile test was done two times for each test parts. A sample specimen for tensile test is shown in Figure 7.

Figure 7. Sample specimen for tensile test (Çekme testi örnek numune)

The tensile values were analysed with the full factorial experimental design method. For example, the results shown in Table 6 were obtained from the variance analysis.

Table 6. Analysis of variance (Varyans analizi)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	26	25128,5	966,48	18,60	0,000
Linear	6	11229,0	1871,50	36,02	0,000
Temp	2	9089,8	4544,91	87,46	0,000
Velocity	2	511,8	255,91	4,92	0,015
Time	2	1627,4	813,69	15,66	0,000

Continuation of Table 6.

2-Way Interactions	12	5101,4	425,12	8,18	0,000
Temp*Velocity	4	1221,9	305,46	5,88	0,002
Temp*Time	4	1866,3	466,57	8,98	0,000
Velocity*Time	4	2013,3	503,32	9,69	0,000
3-Way Interactions	8	8798,0	1099,75	21,16	0,000
Temp*Velocity*Time	8	8798,0	1099,75	21,16	0,000
Error	27	1403,0	51,96		
Total	53	26531,5			

While evaluating the factors affecting the tensile strength value according to the *P* value, the significance level of 5% (α= 0.05) was considered into account. It has been concluded that the factors and interactions whose *P* value is below the significance level affect the tensile strength value statistically. According to the *P* values, it is seen that all factors and interactions affect the tensile strength of the material. According to the sum of squares values, the factors and their effects are shown in Table 7.

Table 7. Tensile strength values sum of squares ratio (Çekme mukavemeti kareler toplamı oranı)

Temperature	34,26%
Velocity	1,92%,
Time	6,13%
Temperature*Velocity	4,60%
Temperature*Time	7,03%
Velocity*Time	7,58%
Temperature*Velocity*Time	33,16%

It is seen in Figure 8 that the factors and interactions that exceed the threshold value (2,05) in the Pareto chart affect the response variable. In the pareto chart shown in Figure 8, it is seen that the temperature factor is the parameter that most affects the tensile strength. This result was reached because the standardized effect value in the graph was at the highest temperature factor. After determining the degrees of freedom of the factors, the t table is checked for the threshold value. Standardized effects are t statistics that test the zero hypothesis that the effect is zero. The zero hypothesis is an assumption used in statistics that suggests that there is no difference between certain features of the data generation process. [12] The threshold value in the Pareto chart is calculated automatically by the statistical analysis program (Figure 8). To summarize, it is seen in the Pareto chart that the factors exceeding the threshold value and the interactions of the factors have an effect on the output.

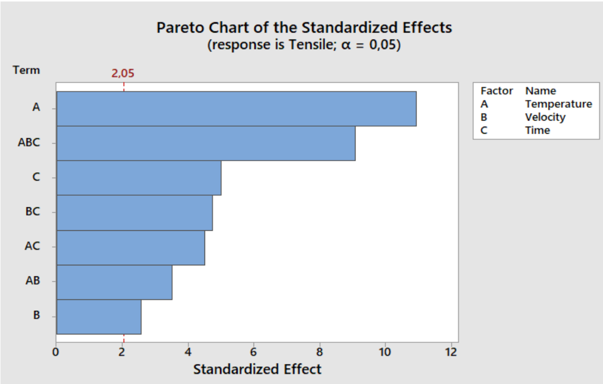


Figure 8. Pareto chart for tensile strength (Çekme mukavemeti pareto grafiği)

When the experimental design model was examined, it was seen that the R-sq value was 94,71% and the R-sq (adj) value was 89,62%. The high R-sq value indicates that the obtained data explains the experimental design model.

The main effects plot also is shown in Figure 9. According to the graph, the highest tensile strength values were obtained when the molten metal temperature was 725 °C, the injection velocity was 2.6 m/s, and the mold opening time was 15 s.

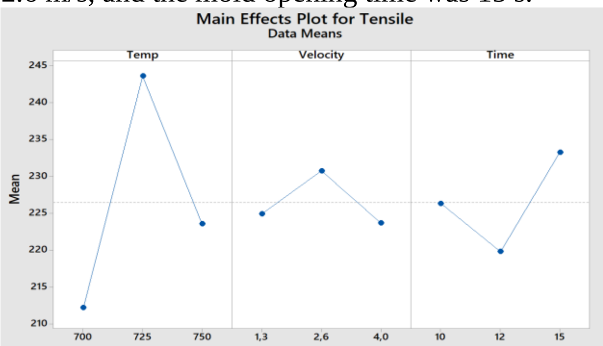


Figure 9. Main effects plot for tensile test (Çekme testi ana etkiler grafiği)

In addition, the 3D graphics shown in Figure 10 have been drawn in order to visualize and better understand the effect of molding factors on the output. Each of these graphs shows the effect of 2 different input parameters on the output.It is seen that the temperature of the material, 725, is the most effective parameter in the 3D plots.

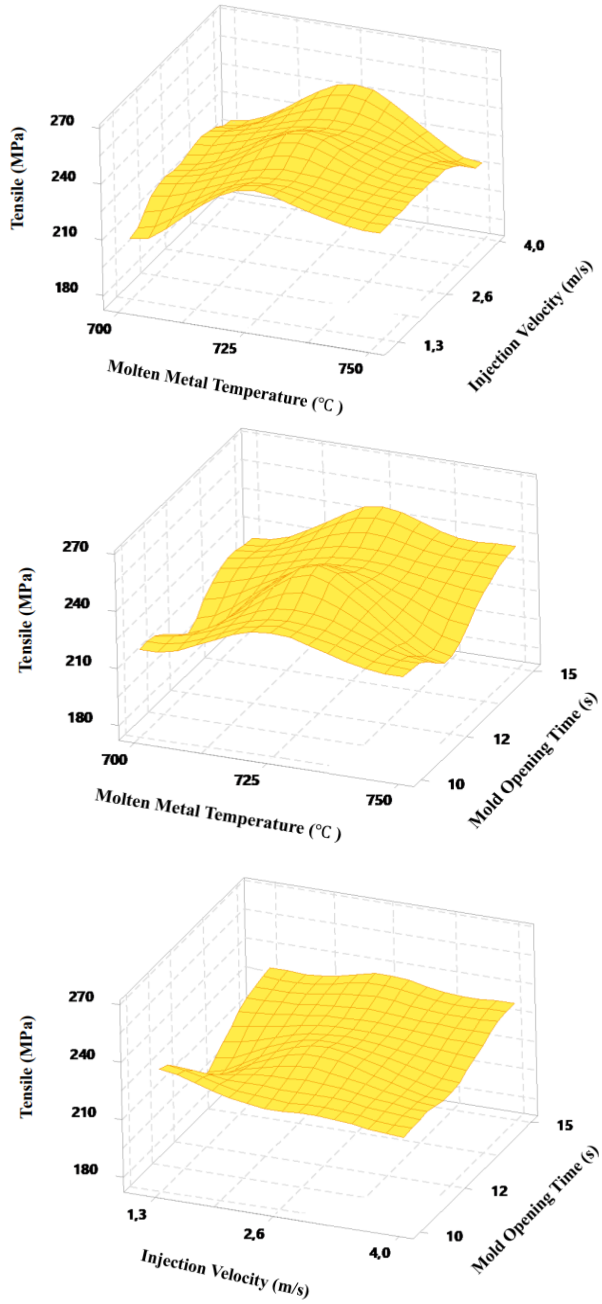


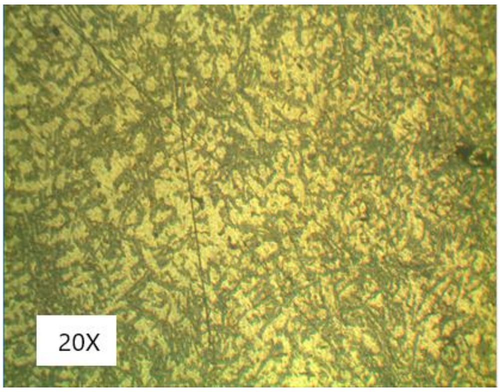
Figure 10. 3D Interaction plots for tensile test
(Çekme testi 3D etkileşim grafikleri)

As a result of the experiments, it has been seen that the parameter that has a great effect on the material strength is the molten metal temperature. When the literature is examined, it has been seen in a previous study that the casting temperature is the parameter that most affects the strength of the product produced by high pressure die casting method using magnesium alloys [5]. In another study, it was observed that the probability of gas porosity increases in the samples produced when the casting temperature is too low. With the increase of gas porosity, the strength of the produced material decreases [13].

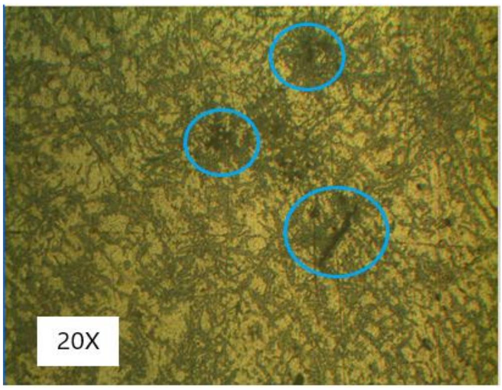
Although no generalization can be made for the hardness and tensile test results, some inferences can be made. When the tensile test specimens were examined, it was observed that there was porosity in the inner parts of the fractured areas. When Figure 9 is examined, it is seen that the worst strength is obtained when the injection speed is 4 m/s, and the best strength is obtained when it is 2,6 m/s. Porosity formation directly affects the strength of the materials. These results similar to results of Koru and Serçe's study. In their study, they stated that 3 and 5 m/s injection velocity parameters increased the formation of porosity, and 2 m/s injection velocity value could be used instead [3].

Increasing the temperature of the molten metal reduces the formation of porosity as it also increases the fluidity of the material, and accordingly, it positively affects the mechanical properties (hardness, tensile strength) of the material. The best strength was obtained at a temperature of 725 degrees in both hardness and breaking strength values. At a temperature of 750 degrees, a decrease in mechanical properties observed. It is thought that this situation is caused by the increase in the amount of oxygen entering between the grains with the increase in temperature and the formation of porosity accordingly. When the produced samples were examined, an increase was observed in the number of porosities.

According to Table 3, it is seen that the tensile strength is lowest in test material 9, and best in test material number 11. Microstructure analysis was made for these two test pieces and the images in figure 11 were obtained with using metal microscope. The purpose of microstructural analysis is to see whether there is a microstructural difference in the samples with the best and worst results.



a)



b)

Figure 11. Microstructure of test specimen 11 (a), microstructure of test specimen 9 (b) (11 numaralı test numunesi mikroyapısı (a), 9 numaralı test numunesi mikroyapısı (b))

When the microstructure results are examined, it is thought that the regions marked with circular shapes are porosities. This situation also explains the lower strength of sample number 9 (Figure 11-b). These differences between microstructures affect the mechanical properties of materials. Especially the gas porosities in the cast materials produced negatively affect the strength of the material.

4. CONCLUSIONS (SONUÇLAR)

In this study, the values of the hardness and tensile tests of the test specimens that were molded by using Aluminum ($AlSi_{12}Cu$) EN AC 47000 alloy according to the determined injection parameters were statistically analyzed with using full factorial design method. In addition, the effect of the injection parameters on the mechanical properties of the molding material was tried to be understood according to the results. The results obtained with the full factorial method are generally as follows:

- In Pareto charts, it is observed that the temperature variable is the parameter that most affects both the tensile strength and hardness value of the produced material. In the results of the factorial analysis, the highest F value was in the temperature variable.
- It was observed that the increase in molten metal temperature increased the hardness value and the highest hardness value was obtained as 85,05 HB(Table 3) in sample number 25 (temperature 750 ℃, injection velocity 1,3 m/s, mold opening time 10 s).
- The factorial analysis for the hardness test results obtained revealed that the highest hardness values were obtained when the molten metal temperature was 725 ℃, the injection velocity was 4 m/s, and the mold opening time was 10 s.
- It has been observed that good results are obtained for tensile strength values when the temperature value increases and the mold opening time is 12 s, and the highest tensile strength value is 264 MPa (Table 3) in sample 11 (temperature 725 ℃, injection velocity 4 m/s, mold opening time 12 s).
- The factorial analysis for the obtained tensile test results, when the molten metal temperature of 725 ℃, the injection velocity 2,6 m/s, the mold opening time was 15 s, the highest tensile strength values were obtained.
- When the 3D interaction graphs in Figures 8 and 12 are examined, it is observed that the results obtained are similar to the main effects graphs.

Moreover, some recommendations that helps to someone who can work in this subject are given in following:

- Heat treatments can be performed on molded samples.
- Machinability tests can also be performed on molded samples.
- Microstructures of the samples can be examined in detail.

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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)

Emre AKKAYA: He conducted the experiments, determined design of experiment, analyzed the results and performed the writing process.

Deneyleri yapmış, deney tasarımını belirlemiş, sonuçlarını analiz etmiş ve makalenin yazım işlemini gerçekleştirmiştir.

Yunus KAYIR: He conducted the experiments and checked the analysis of the test results.

Deneyleri yapmış ve deney sonuçlarının analizlerini kontrol etmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

REFERENCES (KAYNAKLAR)

[1] Ç. Çağan, M. Uğurlu and B. Buldum, Aluminum and Its Alloys Applications in Military Vehicles., in II. International Defense Industry Symposium, Kırıkkale, 2017.

[2] X. Dong, . H. Yang, . X. Zhu and S. Ji, "High Strength and Ductility Aluminium Alloy Processed by High Pressure Die Casting," Journal of Alloys and Compounds, vol. 773, pp. 86-96, 2019.

[3] O. Serçe and M. Koru, "Yüksek Basınçlı Döküm Prosesinde Enjeksiyon Parametrelerine Bağlı Olarak Döküm Simülasyon," Cumhuriyet Science Journal, vol. 36, no. 5, pp. 10-23, 2015.

[4] V. Toptaş, "Bir Alüminyum Alaşımı ile Basınçlı Döküm Yöntemi Kullanılarak Tabanca Gövdesi Üretimi," Istanbul Technical University, Graduate School of Natural and Applied Sciences, Master Thesis, 2014.

[5] F. Mert, A. Özdemir and Ç. Karataş, "Magnezyum Alaşımlarının Basınçlı Döküm Yöntemiyle Kalıplanabilirliğinin Değerlendirilmesi," Journal of Polytechnic, vol. 13, no. 3, pp. 165-176, 2010.

[6] Y. B. Süslü, M. S. Acar, O. Özcan , M. Mutlu and Ö. Keleş, "Yüksek Basınçlı Alüminyum Döküm İle Üretilen Ürün Kalitesine AlTi5B1ve AlB3 Ön Alaşımının Etkisi," in TÜDÖKSAD 2nd Casting Conference, 2019.

[7] M. A. Haque, B. K. Jena and D. K. Mohanta, "Optimization of Process Parameters In Cold Chamber Pressure Die Casting Using DOE," vol. 4, 2017.

[8] M. Mihailescu, A. Negrea, M. Ciopec, P. Negrea, N. Duteanu, I. Grozav, P. Svera, V. Cosmin, A. Barbulescu and C. S. Dumitriu, "Full Factorial Design Gold Recovery from Industrial Solutions," Toxics, vol. 9, no. 5, 2021.

[9] A. Spanelis and A. D. Walker, "A Multi-Objective Factorial Design Methodology for Aerodynamic Off-Takes and Ducts," Aerospace, vol. 9, no. 3, 2022.

[10] I. A. Mohammed, M. T. Bankole, A. S. Abdulkareem, S. S. Ochigbo, A. S. Afolabi and O. K. Abubakre, "Full factorial design approach to carbon nanotubes synthesis by CVD method in argon environment," South African Journal of Chemical Engineering, vol. 24, pp. 17-42, 2017.

[11] G. Akman and C. Özkan, "Sac İmalatında Karşılaşılan Yapışma Probleminin Deney Tasarımı İle Çözümü," Doğuş University Journal, pp. 187-199, 2011.

[12] M. Korkmaz, C. Özmetin, E. Özmetin, E. Çalgan and Y. Süzen, "Boron Removal by Aluminum Modified Pumice and Aluminum Hydroxide from Boron Mine Wastewater-Full Factorial Experimental Design," Nevşehir Bilim ve Teknoloji Dergisi, vol. 10, no. 1, pp. 1-13, 2021.

[13] T. Wang, J. Huang, H. Fu, K. Yu and S. Yao, "Influence of Process Parameters on Filling and Feeding Capacity during High Pressure Die-Casting Process," Applied Sciences, vol. 12, no. 9, 2022.

[14] B.Gökçe and S. Taşgetiren, "Kalite İçin Deney Tasarımı",Makine Teknolojileri Elektronik Dergisi, vol. 6, no. 1, pp. 71-83, 2009.

[15] D.C. Montgomery, Design and Analysis of Experiments, vol. 7th, New York: John Wiley & Sons, 2008.