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Production of Cast Iron Turbocharger Central Housing from Aluminum Alloy

Pik Turbo Orta Göbeğinin Alüminyum Alaşımından Üretilmesi

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Abstract

The goal of this research is to make an aluminum alloy center housing for a turbocharger, which is currently built of cast iron, in order to minimize weight in the car sector. The use of aluminum alloy instead of cast iron to manufacture a turbocharger central housing is expected to result in a 60 percent weight reduction.

It was determined in the investigation that A242 aluminum alloy might be utilized in place of cast iron. The turbo mid-hub, which is comprised of A242 aluminum alloy, was then heat treated and hardness tested. The finite element approach was used to examine the temperature distribution of the part.

As a result of the aging experiment, the solution temperature and duration were kept constant, and the most acceptable aging temperature and time for the turbocharger central housing were identified as 190°C, 234 minutes, as a consequence of the aging heat treatments done at different temperatures. The maximum temperature of the turbo center housing made of A242 alloys and cast iron according to the temperature distribution study is 153°C for aluminum alloy and 233°C for cast iron.

Keywords: *Aluminum, A242, Turbo Cental Housing*

Öz

Bu araştırmanın amacı, otomobil sektöründe ağırlığı en aza indirmek için şu anda dökme demirden yapılmış bir turboşarj için alüminyum alaşımlı bir merkez muhafazası yapmaktır. Bir turboşarjın orta göbeğini üretmek için dökme demir yerine alüminyum alaşımının kullanılmasıyla, ağırlıkta yüzde 60'lık bir azalma beklenir.

Yapılan incelemede dökme demir yerine A242 alüminyum alaşımının kullanılabileceği belirlendi. A242 alüminyum alaşımlı turboşarj merkez muhafazası daha sonra ısıl işleme tabi tutuldu ve sertlik testi yapıldı. Parçanın sıcaklık dağılımı da sonlu elemanlar analizi kullanılarak incelenmiştir.

Sonuç olarak; yapılan yaşlandırma deneyinde çözeltiye alma sıcaklığı ve süresi sabit tutulmuş olup farklı sıcaklıklarda yapılan yaşlandırma ısıl işlemleri sonucunda turbo orta göbeği için en uygun yaşlandırma sıcaklığı ve süresi 190°C, 234 dakika olarak belirlenmiştir. Sıcaklık dağılım etüdüne göre A242 alaşım ve dökme demirden imal edilen turbo merkez muhafazasının maksimum sıcaklığı alüminyum alaşım için 153°C ve dökme demir için 233°C'dir.

Anahtar Kelimeler: *Alüminyum, A242, Turbo Orta Göbeği*

1. Introduction

In passenger automobiles, the engine is the heaviest component. As a result, reducing the engine's weight is the most effective way to improve performance while lowering fuel consumption and emissions. Because of its high-temperature resistance, strength, machinability, and cost-effectiveness, cast iron has been frequently employed as engine material. The primary property that makes aluminum so appealing is its low density (2.7 g/cm^3), which is around one-third that of iron. To achieve high strength and a high strength-to-weight ratio, aluminum can be alloyed and strengthened by cold working and/or heat treatment [1]. For engine applications, aluminum alloys give maximum strength while reducing weight. Aluminum castings have been able to satisfy new market demands because of advancements in aluminum alloys and the selection of appropriate casting procedures. These developments enabled in the replacement of cast iron alloy engine components with aluminum alloys. Aluminum-copper alloys are commonly used in casting components that require both strength and hardness. These alloys have high strength and hardness at room temperature and elevated temperatures. A242.0 alloys are widely used for applications where strength and hardness at high temperatures are required. These alloys are frequently used in motorcycle, diesel pistons, aircraft generator bodies and air-cooled cylinder head [2-5].

In this study, A242.0 was determined as the suitable aluminum alloy in order to produce the turbo mid-hub, which is made of cast iron for weight reduction in the automotive industry, with aluminum alloy. Heat treatment and hardness tests of the part produced from A242 aluminum alloy were carried out. As a result, the temperature distribution analyzes of the part were made using the finite element method package program (ANSYS). [6-8]

Table 1. Determination of the number of tests for the measurement of aging

Aging Temperature (°C)	Measuring Ranges	Measurements to be made	Number of samples used in the experimen
150	Hardness measurement will be taken every 10 minutes in the first hour, every 20 minutes in the second hour, every 20 minutes in the third hour, every 30 minutes in the fourth hour, and hourly in the following hours. It will continue for 20 hours.	5 hardness measurements in every measuring range	28 samples were used for each temperature.
180			
190*			
230			
290			

* The ideal aging conditions were established in the MATLAB application to be 190^{o}C

2. Material and Method

2.1. Aluminum alloy aging treatment

The first stage of the experimental study to begin with determining the aging processing parameters of the aluminum alloy. Table 1 shows the procedure of aging experiments for the turbo central housing casting A242.0.

Turbo central housing was casted by sand casting method. The weight of the turbo central housing is 821.26 g, its diameter is 123.92mm and its height is 47.36 mm. Twenty-nine samples were prepared for aging testing (15x15x30 mm).

Figure 1 shows a photo of the A242 alloy-cast turbo center hub. The element analysis for this part is provided in Table 2.

Figure 2. A242 alloy-cast turbo center hub

Table 2. Elemental analysis of A242 sample.

Alloy	Fe%	Cu%	Mn%	Mg%	Cr%	Ni%	Al%
A242.0	0.54	4.13	0.046	1.47	0.147	1.88	91.5

Twenty-nine samples were subjected to solution heat treatment and 28 of those were subjected to aging heat treatment. Solution treatments were performed at 520℃ temperatures for 7 h, followed by quenching in water. Followed by solution heat treatment, the aging heat treatment was performed at 290°C, 230°C, 190°C, 180°C ve 150°C. At the same temperature 28 samples are placed in the furnace and according to Table 1 the samples take out the furnace and the hardness test applied. An extra sample was stored as a quench without thermal aging treatment and a hardness test was performed on the first.

The all samples were grinded with 80 and 240 SiC grinding paper after the heat treatments process to determine hardness values of samples. Acording to ASTM E384-17, sample preparation should eliminate any damage caused by these steps, such as excessive heating or cold work. [9] Hardness values of the samples were measured using a Shimadzu HSV-30 test machine under a force of 98N was applied for an indentation hold time of 10 s.

2.2 Microstructure and SEM Analysis

The preparation of the samples for optical microscopy and scanning electron microscopy was carried out using procedures grinding and polishing steps. SiC grinding papers until 1200 mesh were used, after that polished using diamond suspension (1 and 3 µm). The sample's surface was then etched to obtain an examination of the microstructure. The etching solution consists of 2 ml HF, 3 ml HCl, 5 ml HNO_3, and 190 ml water. The surface for 20 seconds was immersed in this solution. Then the samples were cleaned by rinsing with ethanol. The samples were examined through optical microscopy using a NICON microscope. The samples were examined also by scanning electron microscopy using a JEOL 6060 microscope, which was operated at an acceleration voltage of 20 kV.

2.3 Temperature distribution analysis

The temperature distribution controls of the part were carried out via the package program (ANSYS) with the finite element method.

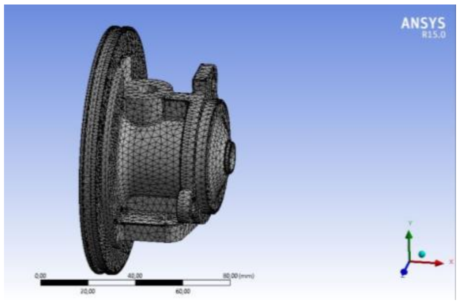

Figure 3. Mesh image of the part

For temperature distribution analysis, the surfaces of the turbo mid-hub are defined when the material properties are entered into the ANSYS program.

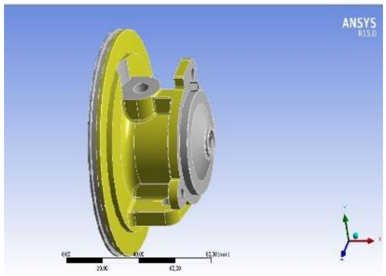

Figure 4. The defined air surface of the part.

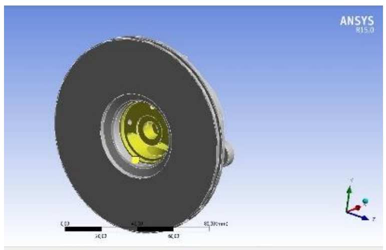

Figure 5. Defined oil surface of the part.

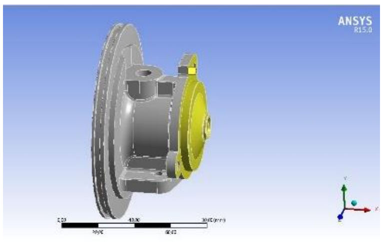

Figure 6. The identified exhaust side of the part.

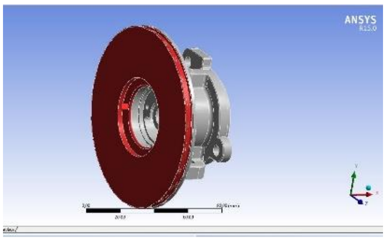

Figure 7. Defined cold surface of the part

First, the part has meshed as shown in Figure 3. Next, the inert air area in Figure 4 is defined. The oil contact area for cooling and bearings is shown in Figure 5. Figure 6 shows the hot exhaust surface near the turbine. Finally, the cool air of the engine and the surface of the compressor side is in Figure 7 determined as seen.

3. Result and Discussion

3.1 Aging

The following graphs show the hardness values taken at regular intervals at 290°C, 230°C, 180°C, and 150°C temperatures for the aging test of the samples.

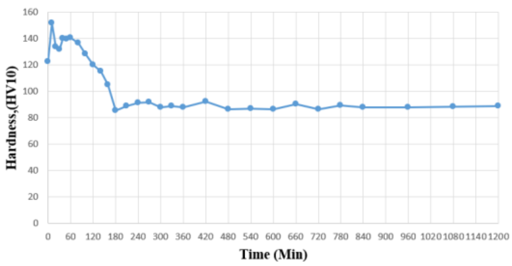

Figure 8. Graph of typical hardness values at 290°C

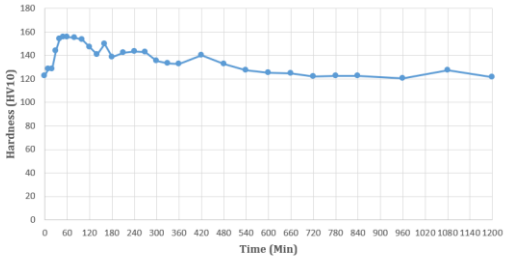

Figure 9. Graph of typical hardness values at 230°C

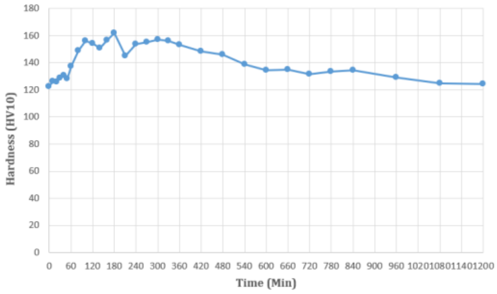

Figure 10. Graph of typical hardness values at 180°C

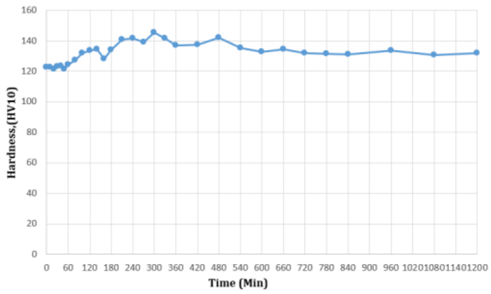

Figure 11. Graph of typical hardness values at 150°C

The samples were aged at 290°C, 230°C, 180°C, and 150°C, respectively, and the measured hardness measures were displayed in a three-dimensional image.

According to Figure 10, the highest hardness value was found at 180°C and 180 minutes. In Figure 12, the hardness values were entered into the MATLAB application and optimized for all temperatures.

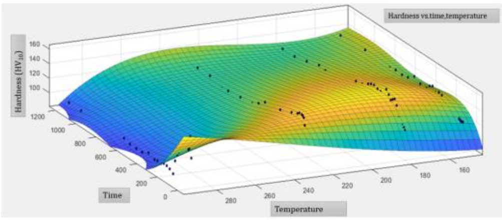

Figure 12. Optimization of aging parameters in MATLAB

Ideal aging conditions have been determined in the MATLAB application at 190°C and 234 minutes. The hardness results following the 190°C aging test are presented in Figure 13.

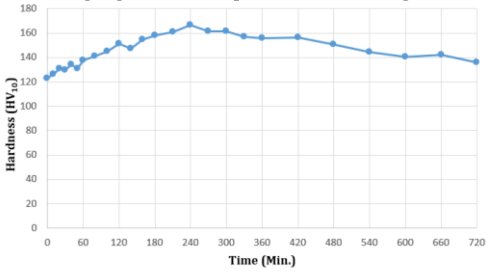

Figure 13. 190°C average hardness values graph.

According to the measured hardness values, 190°C and 234 minutes conditions determined in MATLAB have been proven to be approximately optimum values.

3.2 Microstructure analysis

Samples were conditioned in the furnace for solution heat treatment for seven hours at 520°C, as determined by the literature[1, 8]. Microstructural analyses of the samples were performed using an optical microscope and a scanning electron microscope. An optical microscope image of samples is shown in Figure 14. One of the samples cooled in the oven and the other quenching in water.

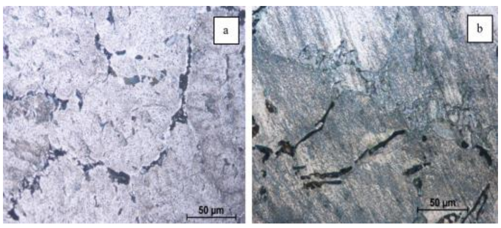

Figure 14. x50 objective, a) Cooled in the oven, b) Quenching in water.

SEM images in BEC mod and EDS analyses of the sample are shown, which was placed in the solution and cooled in the furnace in Figure 15, were quenched in water in Figure 16-17 and were prepared according to the optimum aging parameters in Figure 18-19.

Al-Cu phases precipitated in the microstructure of the sample cooled in the furnace are seen as small precipitated particles in Figure 15.

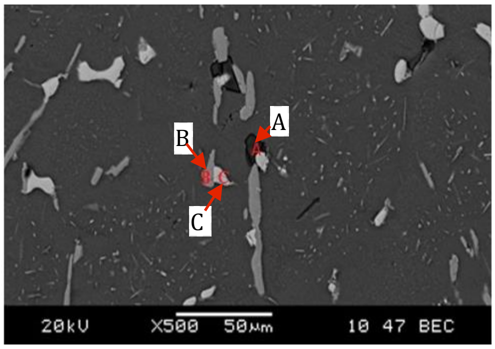

Figure 15. x500 magnification. Selected points in the EDS analysis of the furnace-cooled sample.

Table 3. Elemental compositions of selected points as a result of EDS analysis

%	A	B	C
Al	10.400	64.727	42.725
Cu	0.751	3.475	26.669
Ni	0.164	29.713	29.812
Mg	12.428	0.363	0.265
Si	75.950	1.075	0.065

Also shown in Figure 15, EDS study showed that point A is the precipitated Si particle, point B is Al-Ni particle, and point C contains Al-Cu-Ni elements. When the EDS analyses in Table 3 are compared to the literature review, intermetallic phases such as Al_3Ni, Al_6Cu_3Ni, and $Al(Ni,Cu)_2$ are expected to develop in the structure[1, 8].

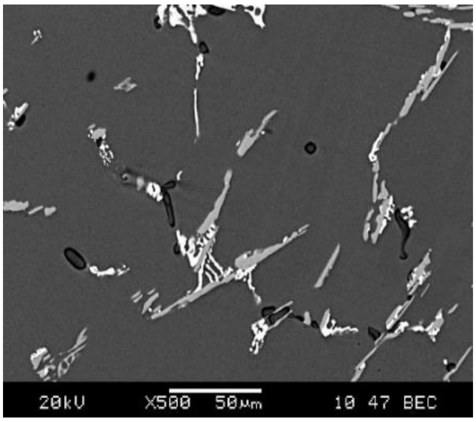

Figure 16. SEM image of the sample cooled by quenching in water at 500x magnification

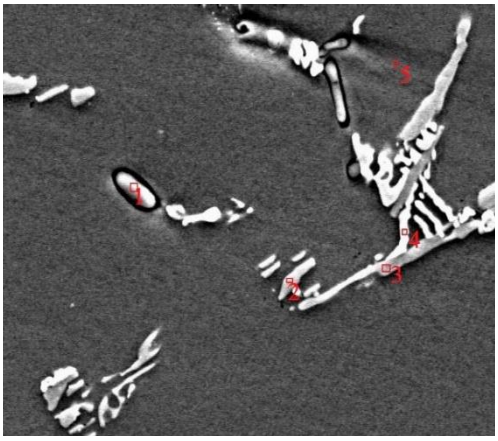

Figure 17. Selected points in the EDS analysis of the sample cooled by quenching in water.

Table 4. Table Elemental compositions of selected points as a result of EDS analysis

%	1	2	3	4	5
Al	9.717	69.608	71.796	51.757	95.550
Cu	0.286	9.088	5.246	27.823	2.838
Ni	0.134	20.279	21.476	19.753	0.316
Mg	2.073	0.412	0.523	0.558	1.133
Si	87.097	0.612	0.957	0.109	0.163

There is no precipitation in the microstructure of the sample cooled by quenching in water. It was observed that there was a Si particle at 1 point, Al-Ni elements were found together at 2 and 3 points, Al-Cu-Ni elements were found together at 4 points, and aluminum element was found in matrix at 5 points.

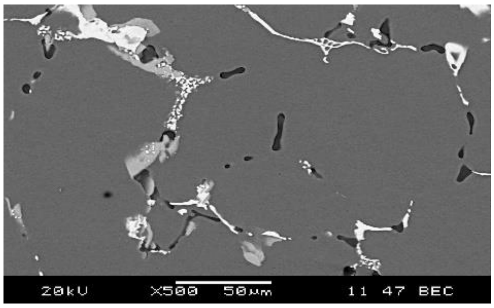

Figure 18. SEM image of the sample prepared under optimum aging conditions at x500 magnification.

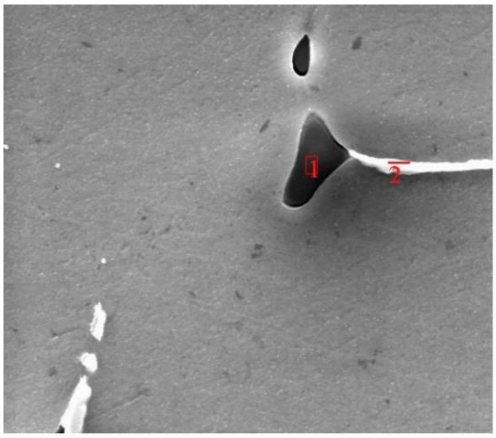

Figure 19. The selected points in the EDS analysis of the sample prepared under optimum aging conditions

Table 5. Elemental compositions of selected points as a result of EDS analysis

%	1	2
Al	16.866	73.339
Cu	0.434	14.695
Ni	0.584	10.954
Mg	5.977	0.887
Si	76.139	0.125

The microstructure of the sample obtained in optimum aging conditions has been not observed any precipitation because of low magnification. It was observed that there is a Si particle at point 1 and Al-Cu-Ni elements together at point 2.

3.3 Temperature Distribution Analysis

The temperature distributions as a result of the material properties entered into the ANSYS program are shown in Figures 20 and 21 for the temperature distribution analysis.

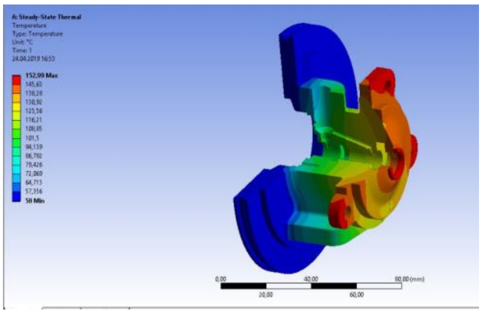

Figure 20. Temperature distribution for aluminum alloy

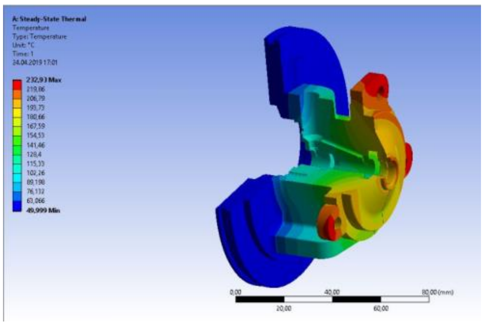

Figure 21. Temperature distribution for cast iron.

It was determined that the temperature of the part produced from aluminum alloy increased to a maximum of 153°C, while the part produced from cast iron increased to a maximum of 233 °C. The reason for this is that the thermal conductivity coefficient of aluminum alloy is higher than that of cast iron.

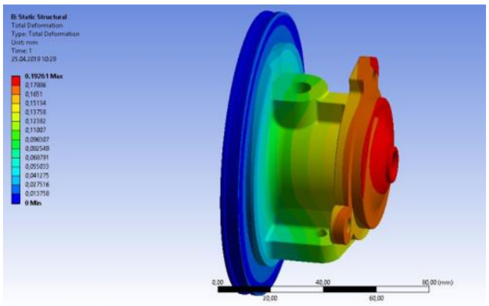

Figure 22. Total deformation for the aluminum alloy.

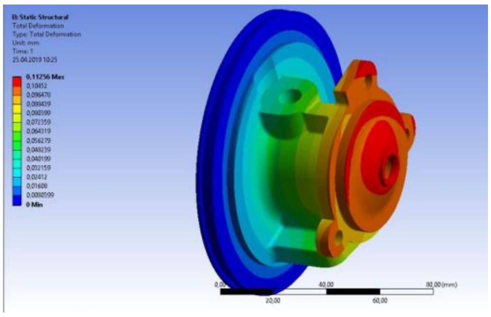

Figure 23. Total deformation for cast iron

The total amount of deformation on the hottest surface of the aluminum alloy portion, namely the exhaust surface, is 0.193 mm, whereas the part constructed of cast iron is 0.113 mm. This result has emerged because the thermal expansion coefficient of cast iron is lower than that of aluminum alloy. However, since this deformation parallels the turbocharger shaft, it has little effect on the operation of the bearing of the part.

Table 6. Heat power distribution table

Surface	Aluminum	Cast Iron
Heat Power of Total Incoming Air by Exhaust (Watt)	481,02	418,59
Heat Power on Air Surface (Watt) **(1)**	-34,75	-33,66
Heat Power on Oil Surface (Watt) **(2)**	-256,21	-276,24
Heat Power on the Cold Surface (Watt) **(3)**	-190,06	-108,69

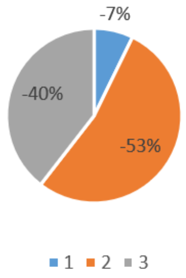

Figure 24. Heat power distribution for aluminum

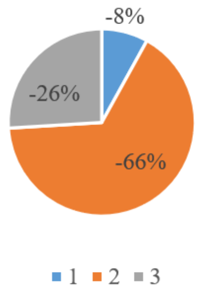

Figure 25. Heat power distribution for cast iron

According to Table 6 and Figure 24 and 25, aluminum heats the air entering the engine more than cast iron. The air enters the intercooler before reaching the engine. The intercooler has to performed decrease the temperature of pressured air to use an aluminum turbo center. Engine power loss does not occur unless the pressure and temperature of the engine intake air change.

4.Result and Discussion

The goal of this research is to find the right heat treatment settings so that the turbocharger center hub may be made of A242 aluminum alloy instead of lamellar graphite cast iron. The heat treatment characteristics of the aluminum-based A242 alloy, which is expected to offer an alternative to lamellar graphite cast iron, were investigated using sand casting. Samples were prepared from the cast aluminum alloy. The results obtained as a result of the experiments are given below:

As a consequence of all of the tests, it has been concluded that A242 aluminum alloy could be used instead of cast iron for the turbo mid-hub. The research by Jing in 2013 uses cast iron GGG400SiMo as a turbocharger housings material suitable for 600°C [10]. Continental's turbocharger with water-cooled aluminum turbine housing entered series production in 2014 on BMW's and MINI's engines [11]. But nowadays almost all turbocharger center housing in diesel engines is already gray cast iron.

As a consequence of the aging test data entered into the MATLAB application, the optimal aging parameters were determined to be approximately 234 minutes at 190°C temperature. The aging treatment was carried out at 190°C. Experimental data indicate that it obtains a maximum hardness value at 230 minutes.

Based on the temperature distribution analysis made in the ANSYS program, it was observed that the temperature of the part produced from aluminum alloy increased to a maximum of 153°C, whereas the part made of cast iron increased to a maximum of 233°C. The reason for this is that the thermal conductivity coefficient of aluminum alloy is higher than that of cast iron. The hottest surface of the aluminum alloy part, that is, the entire amount of deformation on the exhaust surface, is 0.193 mm, whereas the cast iron part is 0.113 mm. The reason for this is that the thermal expansion coefficient of cast iron is lower than that of aluminum alloy. However, because it is parallel to the shaft, it has little effect on the part's bearing function. Additionally, cast iron heats the air entering the engine less than aluminum. However, since the air enters the Intercooler before reaching the engine, it makes little real difference.

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