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# Optimization with Taguchi Method of Laser Parameters Necessary for Smooth Groove Bottom in ZAMAK 5

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**Keywords:**
Laser machining,
ZAMAK5,
Nd: YAG Laser,
Optimization,
Laser Ablation,
Taguchi Method.

**Abstract:** In this study, groove-shaped cavities were created with Nd: YAG laser on ZAMAK 5 plates, which have been used frequently in the industry for many years. The necessary laser parameters have been optimized so that the created cavity floor has a homogeneous depth. The effects of the beam diameter, laser energy, shielding gas type, and duration of the single pulse of Nd: YAG laser used on the roughness in the cavity were tried to be optimized. It was used for optimization. According to the ANOVA table, the optimum parameters are "580µm, 7J, Nitrogen, 7 ms for spot diameter of spot, the energy of single spot, type of ambient gas and a spot of single pulse respectively. The Taguchi method also indicates how effective the laser parameters used are in obtaining the desired surface. It has been concluded that the ambient gas used is the most important parameter in this study. The effect rate was obtained as 74.90 %. Then, laser spot diameter and pulse energy and lastly pulse duration are fewer effective parameters respectively.

# ZAMAK 5'te Pürüzsüz Oluk Tabanı İçin Gerekli Lazer Parametrelerinin Taguchi Yöntemi ile Optimizasyonu

**Anahtar Kelimeler:**
Lazer işleme,
ZAMAK5,
Nd:YAG Lazer,
Optimizasyon,
Lazer Ablasyon,
Taguchi Metodu

**Özet:** Bu çalışmada uzun yıllardır sektörde sıklıkla kullanılan ZAMAK 5 plakalar üzerinde Nd: YAG lazer ile oluk şeklinde kaviteler oluşturulmuştur. Oluşturulan kavite tabanının homojen bir derinliğe sahip olması için gerekli lazer parametreleri optimize edilmiştir. Kullanılan Nd: YAG lazerin ışın çapı, lazer enerjisi, koruyucu gaz tipi ve tek atım süresinin kavite pürüzlülüğü üzerindeki etkileri optimize edilmeye çalışılmıştır. ANOVA tablosuna göre, spot çapı, tek spot enerjisi, ortam gazı türü ve tek darbe spotu için optimum parametreler sırasıyla "580µm, 7J, Nitrogen, 7 ms'dir. Taguchi yöntemi, kullanılan lazer parametrelerinin istenilen yüzeyin elde edilmesinde ne kadar etkili olduğunu da göstermektedir. Kullanılan ortam gazının bu çalışmada en önemli parametre olduğu sonucuna varılmıştır. Etki oranı %74.90 olarak elde edilmiştir. Daha sonra sırasıyla lazer spot çapı ve atım enerjisi ve son olarak atım süresi daha az etkili parametrelerdir.

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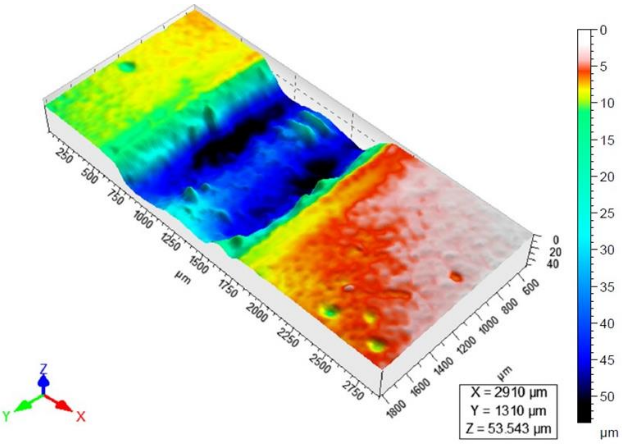
**Graphical Abstract**




## 1. INTRODUCTION

Considering its density and durability, Zinc (Zn), which is superior to polymers, also comes to the fore with its durability. Zn alloys have been widely preferred by application in marine, aerospace, and especially automotive industries due to their superior properties (Zhang et al., 2019). Zamak is used in various places in the car, from seat belts, airbags, engine covers, gearbox parts, and control groups to brackets and carriers. Aluminum and copper content in the ZnAl4Cu1 (Zamak 5) alloy improves mechanical strengthening (Vojtech et al., 2011). Among Zn alloys, Zamak is used in many small parts of automobiles during the casting process since Zamak can be easily shaped, electroplated, wet painted, and chromate conversion coated well. Besides Zamak is used in various places in the car such as seat belts, airbags, engine covers, gearbox parts, control groups, brackets, and carriers, it is also used in door hinges and locks, door handle bodies, various garden equipment, refrigerator door handle, and shelf brackets, washing machine hinges, various parts of gas and electrical appliances, etc. Some properties of materials such as bonding, joining, and friction can be improved by treating their surface (Etsion, 2005). Creating patterns on a surface such as a groove, dimple, etc, can be improved on the surface of the unmachining material. The properties of the surfaces can be changed by manipulating the surface roughness in accordance with the purpose such as the wettability (Kubiak et al., 2011; Holmberg et al., 1998; Perveen and Feng, 2017; Raeesi et al., 2013), friction (Kubiak et al., 2011; Menezes et al., 2009; Kubiak and Mathia, 2009), joining and bonding (Somekaw and Higashi, 2003; Hirose et al., 2006; Cardella et al., 2004; Chen et al., 2014, Yılbaş, 1987), etc. The joining and bonding properties of the surfaces are very tightly dependent on the roughness of the surface (Somekaw and Higashi, 2003). Hiroshe et al demonstrated the effect of surface roughness on the bonding of surfaces with their studies (Hirose et al., 2006). Similarly, Cardela et al also numerically demonstrated the effects of roughness on HIP bonding (Cardella et al., 2004). For some functional or aesthetic reasons, it is necessary to make the alloy surface with the desired properties before processes such as chroming or varnishing. The surface of Zink and its alloys are treated with different kinds of techniques. Although the materials and their surfaces can be processed with various methods, two important features such the precision of the processed surface and the cost of surface treatment, bring LST to the fore in the processing of surfaces with Laser Surface Texturing (LST) (Etsion, 2005). Since the laser parameters can be controlled very widely, the laser parameters can be adjusted appropriately to avoid undesirable situations such as heat deformation when processing with Surface Texturing (LST). In material processing using laser, many parameters affect the result at different rates. Both the parameter selection and the effect of the selected parameters on the result have a great role in the product obtained. For this reason, this study has two main aims. The first is to find out which levels of the selected parameters will give the best results. The second aim is to determine the effect ratios of the selected parameters. Determining the effect ratios will facilitate parameter selection in similar studies from now on.

Each of the laser parameters used can affect the result differently, albeit to a different extent. Changing the focus position up or down effects the spot diameter of the material. As a result, the intensity of the laser beam decreases or increases. Similarly, the laser beam energy is directly related to the amount of energy transferred to the material. In order to prevent the burning of materials with a laser or to control the desired or desired chemical reactions on the surface, trials are usually carried out in a gaseous environment. In this study, the effects of the gases used on the cavity roughness were investigated. Laser pulse duration is one of the important parameters in laser-material interaction. Controlling the pulse duration, energy transfer to the laser, and heating-cooling times affect the shape of the cavity formed.

In this study, the above-mentioned four parameters were examined at three levels. In classical experimental systems, $3^4$=81 experiments should be performed for this examination and the results of these experiments should be analyzed. Instead, by using the Taguchi Optimization Method, an optimum result can be obtained with a total of 10 trials and analyses, including a confirmation experiment in addition to 9 experiments. In addition, the effects of these parameters on the desired result can be calculated (Yılbaş, 1987; Yang and Tarng, 1988; Pana et al., 2004).

## 2. MATERIAL AND METHOD

### 2.1. Taguchi Method

The steps to be followed in a study to be carried out according to the Taguchi Experimental Design technique are as follows (Yang and Tarng, 198):

1. Selection of factors and evaluation of their interactions.
2. Determination of the levels of factors.
3. Choosing the right balanced design.
4. Matching the factors and/or their interactions with the columns in the balanced experimental setup.
5. Analysis of results.
6. Conducting confirmation experiments.

The signal value used in the Taguchi method represents the actual value given by the system and intended to be measured, and the noise factor represents the share of undesirable factors in the measured value. In the calculation of the signal/noise ratio, the quality value aimed to be achieved as a result of the experiments is also important. There are three main categories here:

• low value is the best (target to reach the lowest value)
• high value is the best (the goal is to reach the highest value)
• nominal value is the best (target is to reach a nominal value)

### 2.2. Material and Analysis

A pulsed Nd: YAG (neodymium-doped yttrium aluminum garnet) laser has a maximum scanning speed of 500 Hz. The duration of a single pulse can be adjusted from 0.3 ms to 50 ms. It was used to create grooves on the surface of the examined material. The focus diameter is 400 μm which is the minimum value. When the laser beam is focused on 1, 2, and 3 mm on the material, the spot diameter is 580, 730, and 930 μm, respectively. The energy of each pulse was also adjusted to be 10, 15, and 20 J. Experiments were also carried out in an environment of pure oxygen and nitrogen beside the air environment. The pulse durations of the pulses are arranged as 3, 5, and 7 ms. To reduce possible errors, 5 of each groove were made. The obtained surfaces were examined with a high-resolution microscope and a profilometer. The parameters used in the experiments and the levels of these parameters are given in Table 1. As seen in the table, 3 levels of 4 independent laser parameters were examined.

**Table 1.** Parameters of experiment and levels

| | 1 | 2 | 3 |
|---|---|---|---|
| **Diameter of single spot (μm)** | 600 | 750 | 950 |
| **Energy of single pulse (J)** | 5 | 10 | 15 |
| **Type of ambient gas** | $O_2$ | Ni | Air |
| **Duration of a single pulse (ms)** | 10 | 15 | 20 |

As seen in Table 2, experiments were designed according to using the parameters suggested by Taguchi Method

**Table 2.** Experiment sets

| Experiment no | Diameter of spot (μm) | Energy of single pulse (J) | Type of ambient gas | Duration of a single pulse (ms) |
|---|---|---|---|---|
| **1** | 600 | 5 | $O_2$ | 10 |
| **2** | 600 | 10 | N | 15 |
| **3** | 600 | 15 | Air | 20 |
| **4** | 750 | 5 | N | 20 |
| **5** | 750 | 10 | Air | 10 |
| **6** | 750 | 15 | $O_2$ | 15 |
| **7** | 950 | 5 | Air | 15 |
| **8** | 950 | 10 | $O_2$ | 20 |
| **9** | 950 | 15 | N | 10 |

## 3. RESULTS AND DISCUSSION

After the surfaces were processed with laser, profilometer images of each surface were examined and roughness was calculated from the images. Based on the surface average of the cavity floor, the peaks are positive and the deeps are negative, relative to the average. Accordingly, the nominal value for the desired roughness is defined as zero. Laser parameters that give zero value for the surface roughness are the perfect values. So, laser parameters that also give the surface roughness value closest to zero can also be defined as optimum parameters. According to the Taguchi method, the signal-to-noise ratio for nominal the best characteristics can be calculated with Eqn. 1.

$$S/N_{NB} = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}(y_i - m)^2\right] \quad (1)$$

The roughness values of the bottoms of the cavities obtained as a result of the experiments with the parameter levels given in Table 2 are given in Table 3. These roughness values and the signal-to-noise ratios are made according to Eqn. (1) are also shown in Table 3. The statistical reliability of results can be obtained with the summing of the sum of squares, using Eq. (2) as seen in Table 4.

$$SS_T = \sum_{i=1}^{n}\left(\eta_i - \eta_m\right)^2 \quad (2)$$

**Table 3.** Measured values Roughness with calculated S/N

| Exp. no | Surface Roughness Measurements | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3th | 4th | 5th | mean(μm) | S/N |
| **1** | 100.52 | 96.45 | 98.28 | 109.36 | 104.32 | 101.79 | -40.16 |
| **2** | -15.16 | -55.23 | -41.32 | -51.12 | -45.15 | -41.60 | -32.85 |
| **3** | 61.23 | 51.28 | 46.28 | 55.16 | 50.48 | 52.89 | -34.51 |
| **4** | 45.14 | 35.32 | 39.15 | 51.14 | 39.98 | 42.15 | -32.57 |
| **5** | 88.15 | 81.25 | 77.56 | 74.12 | 88.15 | 81.85 | -38.28 |
| **6** | 100.23 | 101.25 | 99.84 | 88.89 | 110.25 | 100.09 | -40.03 |
| **7** | 85.25 | 98.95 | 105.12 | 101.12 | 90.25 | 96.14 | -39.68 |
| **8** | 210.36 | 205.18 | 89.25 | 220.12 | 216.25 | 188.23 | -45.79 |
| **9** | 51.23 | 54.15 | 46.25 | 45.12 | 65.23 | 52.40 | -34.47 |

**Table 4.** ANOVA table for optimum roughness. (EoF), (OL) and (OV) represent, Effect of factors, Optimum levels, and Optimum Value respectively

| | Average S/N | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1st level | 2nd level | 3rd level | $D_{of}$ | $SS_i$ | Variance | EoF | OL | OV |
| **Spot Diameter** | -35.84 | -36.96 | -39.98 | 4 | 27.51 | 6.88 | 18.15 | 1 | 600µm |
| **Pulse Energy** | -37.47 | -38.97 | -36.33 | 4 | 10.51 | 2.63 | 6.94 | 3 | 15 J |
| **Gas Type** | -41.99 | -33.30 | -37.49 | 4 | 113.51 | 28.38 | 74.90 | 2 | N |
| **Pulse Duration** | -37.64 | -37.52 | -37.62 | 4 | 0.02 | 0.01 | 0.02 | 2 | 15 ms |
| **Total** | | -37.59 | | | 151.55 | | 100 | | |
| **Optimum S/N** | | | | | | | | | -30.21 |
| **Optimum roughness** | | | | | | | | | 33.40 |

The highest levels and values expected S/N were calculated and presented in Table 4.

$$\eta = \eta_m + \sum_{i=1}^{j}(\eta_i - \eta_m) \quad (3)$$

The effect rate was obtained as 74.90 % for the type of ambient gas as the most important parameter. Then, laser spot diameter and pulse energy and lastly pulse duration are less effective parameters respectively as seen in Table 4.

A confirmation experiment was conducted with the parameters suggested by the method to obtain the best result, 600 µm for focus spot diameter, 15 J for the energy of a single pulse, Nitrogen for the type of ambient gas, and 15 ms for the duration of a single pulse. The roughness was calculated as 37.43 on the images of the cavity floor obtained as a result of the verification experiment with a profilometer. Although this result is not better than the result predicted by the Taguchi method, it is a better result than the results obtained with the previous 9 experiments.

## 4. CONCLUSION

The roughness of the base of the Nd: YAG laser-formed grooves on the Zamak 5 surface was investigated. In this study, it is desired that the roughness of the groove floor is minimum. In this study, it is desired that the roughness of the gutter base is minimal. Optimum parameters can be obtained by performing 81 experiments in standard experimental work for 4 parameters and 3 levels. However, with the Taguchi method, the parameters giving the best results were obtained in 9 studies. The result of the confirmation experiment is very close to the predicted result of the Taguchi method, proving that the Taguchi method is applicable in similar studies.

In addition, with the Taguchi method, the most important parameters were determined together with their effective rates. With this result, the most important parameters can be considered in future similar studies.

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