T.C.
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LIFE IMPROVEMENT STUDIES IN SEGMENT-CUT NUT MOLD USED IN COLD FORMING OPERATIONS

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THESIS APPROVAL

The thesis titled "Life Improvement Studies in Segment-Cut Nut Mold Used in Cold Forming Operations" prepared by Bülent ÖZDEN was successfully defended as a MASTER'S THESIS on 24/04/2023 at Celal Bayar University, Institute of Science and Technology, Department of Mechanical Engineering, in front of the following jury members.

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UNDERTAKING

I declare that this thesis was written in Manisa Celal Bayar University, Faculty of Engineering, Department of Mechanical Engineering, in accordance with academic and ethical rules, and that all literature information used is included in the thesis with reference.

Bülent ÖZDEN

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LIST OF SYMBOLS AND ABBREVIATIONS

WC Wolfram Carbide

CO Cobalt

CTE Ceratizit Extra Coarse

CTM Ceratizit Medium

AFM Abrasive Flow Machine

APRX Approximately

CNC Computer Numeric Control

CAD Computer Aided Design

C45 %0.45 Carbon Steel

M Metric

HRC Hardness Rockwell

MPa Megapascal

Ra Roughness Average

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To my thesis assistant Prof. Dr. Nurşen SAKLAKOĞLU, who did not spare her help at every stage of my thesis, for their support in various parts of my thesis, MITTEL A.Ş. co-founder and sales manager Can TEMİZEL, R&D specialist Emre SANDAL, quality engineer H.Deniz EROĞLU, R&D manager M.Burak TOPARLI, R&D executive Gökay YALDIZ, R&D senior specialist Doğuş ZEREN and Tayfur YAVUZBARUT, milling department team leader Gökhan BAĞBOZAN and erosion department team leader Murat ÇETİNKAYA, I would like to express my endless thanks and regards.

Bülent ÖZDEN
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ÖZET

Yüksek Lisans

Soğuk Şekillendirmede Kullanılan Segment Kesimli Somun Kalıbında Ömür İyileştirme Çalışmaları

Bülent ÖZDEN

Manisa Celal Bayar Üniversitesi

Fen Bilimleri Enstitüsü

Makine Mühendisliği Anabilim Dalı

Danışman: Prof. Dr. Nurşen SAKLAKOĞLU

Bu tez çalışmasında, soğuk dövme işleminde kullanılan 4.istasyon somun kalıbının üretim aşamasındaki bazı proseslerde iyileştirme ve geliştirmeler yapılarak ömür artışı hedeflenmiştir. Kalıpta çalışma sonrası hasarlar incelenmiş ve gerekli iyileştirmeler için bir plan oluşturulmuştur. Öncelikle aynı kalıbın yurtdışından tedarik edilen bir muadili incelenmiş ve aradaki farklar gözlemlenmiştir. Ardından mevcut kalıpta üzerinde çalışılacak olan prosesler belirlenmiştir. Kalıpta kullanılan malzemeler 1.2344 takım çeliği, 1.4140 takım çeliği ve sanayide geçen ismiyle elmas (Tungsten Carbide) sert metaldir. Kalıpta ayrıca ön ve taban olmak üzere iki çeşit elmas bulunmaktadır. Bunların da cinsleri sırasıyla CTE35 ve CTE50'dır. CT tedarikçi firma olan Ceratizit'i temsil ederken, E tanecik boyutu olan Extra Coarse'u 50 ise Tungsten Carbide içindeki kobalt oranının (%25) iki katını temsil etmektedir. Segment kesimli somun kalıbı üretim aşaması olarak yaklaşık 25 operasyondan oluşur ve süreç olarak en uzun sürede üretilen kalıp çeşitlerinden bir tanesidir. Yüksek lisans tezi kapsamında ise iyileştirme ve geliştirme için bu operasyonlardan 4 tanesi üzerine yoğunlaşılmıştır. Bunlar tel erezyon tezgâhlarında uygulanan segment kesim işlemi, taban formu oluşturmada kullanılan dalma erezyon işlemleri, CNC tornalardada yapılan flanş formu işlemesi ve son olarak parlatma prosesleridir. Bu operasyon değişiklikleri de bakır elektrot yerine karbür alaşımlı bakır kullanmak, kalıp ağzındaki radyüsleri spiral taşla manuel olarak oluşturmak yerine radyüs formlu bakır ile işlemek, farklı bir ön elmas cinsi kullanmak ve manuel parlatma yerine otomatik parlatma makinesi devreye alma işlemleridir. Yapılan değişiklikler birlikte kalıplarda yurtdışı muadillerini yakalayacak seviyede bir ömür artışı hedeflenmektedir.

Anahtar Kelimeler: Soğuk şekillendirme, somun kalıbı, elmas (sert metal), kobalt, tel erezyon, dalma erezyon, beyaz tabaka.

2023, 70 Pages

ABSTRACT

M.Sc. Thesis

Life Improvement Studies in Segment-Cut Nut Mold Used in Cold Forming Operations

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In this thesis, it is aimed to increase the lifetime by making improvements in some processes in the production phase of the 4th station nut mold used in the cold forging process. Damage after working on the mold were examined and a plan was created for the necessary improvements. First of all, an equivalent of the same mold supplied from abroad examined and the differences were observed. Then, the processes to be worked on the existing mold were determined. The materials used in the mold are 1.2344 tool steel, 1.4140 tool steel and hard metal ‘’diamond’’ (Tungsten Carbide)as it known in the industry. The mold also has two kinds of diamonds, front and base. Their types are CTE35 and CTE50 respectively. While CT represents Ceratizit, the supplier company, Extra Coarse (E) and Fine (F) are the grain size of the diamonds. 50 is represent twice the cobalt ratio (%25) in the tungsten carbide. Segment cutting nut mold production consist of 25 operations approximately and is one of the mold types produced longest time as a process. Within the scope of the master’s thesis, 4 of these operations have been focused of for improvement and development. These are Segment cutting process applied in wire erosion benches, the plunge erosion processes used in the forming the base form, the flange form processing performed in the Cnc Turning, using different type of front diamond and finally polishing process. If the expected life increase can not be achieve, some operations were directly changed instead of operational improvements. These operation changes are using the copper with the carbide content instead of the bottom form machining in plunge erosion with the help of plain copper electrode and automatic polishing machine activation instead of manuel polishing. With the changes made, a significant increase in the life of the molds is aimed.

Keywords: Cold forging, nut mold, hard metal, cobalt, wire erosion, diving erosion, white layer.

2023, 70 Pages

1.INTRODUCTION

Forging is defined as a method of giving plastic shape to materials in hot, semi-hot or cold form under the influence of forces applied in the vertical direction [1].

This process is called hot forging if it is done at a temperature above the recrystallization temperature of the material, and cold forging if it is done at room temperature [2].

Shaping with the forging process is preferred due to the fact that more sensitive product forms are obtained than other plastic deformation methods. In addition, cold forming process is used for the production of complex workpieces, since the final product measurement precision tolerances are very low since it is carried out at room temperature, it allows rapid production, and the surface and mechanical properties of the final product are much more advanced than the parts produced by alternative production methods, adopted as the most useful method [3].

Fixed and movable presses used in cold forming consist of 2, 3, 4, 5 or 6 stations according to the form of the material to be produced. The product is shaped by transferring between stations with the help of fingers [4]. Since the final form cannot be given to the main material in a single station, the number of stations increases according to the complexity of the product.

During the shaping of the material with the cold forging process, depending on the geometry of the material produced and the material type, the molds are overloaded and breakages may occur due to this. When the causes of fracture are examined, the main factors are wear [5], crack formation and fatigue [6] and plastic deformation [7].

In recent years, many studies have been carried out on the molds used in the production of fasteners by cold forming method. Life analysis of these molds used in the production of nuts and bolts is the most common technical simulation technique. In this way, life analyzes such as die lifetimes and punch lifetimes used in cold forming can be made.

Within the scope of this thesis, similar studies in which mold lifetimes were analyzed were examined. A brief summary of some of these studies is as follows;

Skov – Hansel et al., in their study, used prestressing and jamming conditions in the analysis of molds [8].

Fu et al., using the finite element method in their study, investigated the fatigue life due to stress and obtained results close to reality [9].

In their study, Erbil and İnce stated that the use of simulation method in cold forging process both increases product quality and reduces costs [10].

One of the biggest problems encountered in cold forging processes is the breaking of dies in early cycles due to high forging forces and heavy friction conditions [11]. The most common form of fracture in molds is fatigue fractures that occur under dynamic repetitive high pressing power [12].

As a result of the high and repeated impact load during the cold forming process, micro cracks occur on the mold surface. As a result of the progression of these invisible micro cracks, breakage occurs in the molds. The microcracks formed during these fatigue fractures start from the point of the highest stress and progress according to the stress topography [13]. For this reason, understanding and preventing these breakage mechanisms in molds is very important in terms of reducing production costs. Thus, a great advantage can be obtained in terms of competition with the companies in the market [14].

Cold forging dies consist of tungsten carbide – cobalt (WC – Co) core material, which has high compressive strength and produced by powder metallurgy, and steel outer envelope materials with high tensile strength, with tight fit ratios ranging from 0.2% to 0.7%. The purpose of the shrink fit process is to absorb and minimize these stresses in the core diamond material, which is exposed to tensile stresses, by creating a compressive force [15].

Accuracy control of cold forging processes can be divided into two phases: (1) preparatory phase; (2) production.

The preparatory phase consist of process planning, tool designing, tool manifacturing and machine selection. It can be stated that this phase is the most important one: non-optimal solutions can cause anbormal tool wear and loads, which can result in moving of the process to an unstable area [19].

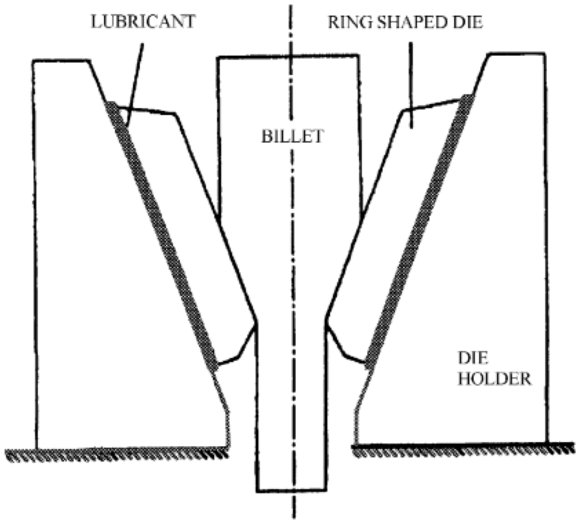


Figure 1.1 Cold Extrusion Tool with Controlled Die Information

Meidert and Hansel, studied the tool lifespan for typical net shape cold forging parts produced for the automotive industry (Figure 1.2(a)). It should here be noted that the failure mode in this study was primarily fatigue failure or over load and rarely wear failure. The life span observed ranges from a few hundred up to 90,000 strokes. This variation must be better understood in order to make microforming a viable process [20].

Table illustrated qualitatively the causes of tool failure as a function of tool hardness as shown in (Figure 1.2 (b)). It is suggested based on this figure that maximum tool life is not given by maximum hardness but that there is an optimum hardness. It is, however, important to bear in mind that as formed parts are getting smaller and more complicated, the necessary local pressures increase necessitating harder tools. Fatigue failure has a strong stochastic nature which will be discussed more in detail below [20].

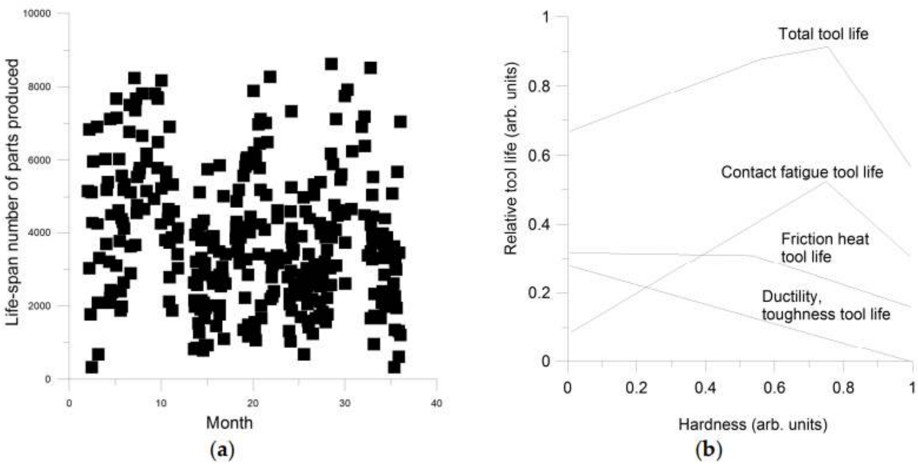


Figure 1.2 Tool Life Data of Life Spans of Individual Tool Inserts (a), Schematic Relation Between Tool Hardness and Reason for Failure in Tooling (b)

The texture of die surface plays an important role in the tribology of metal forming processes. The surface texture is defined by surface roughness and its orientation, which is influenced by the manufacturing processes.

In this research, the effects of various die machining operations on the frictional condition in the forming process of C45 steel are investigated by means of ring compression test. The dies are fabricated through six machining operations, including horizontal and vertical milling, electrical discharge machining, grinding, polishing and turning. Moreover, the ring specimens are compressed by parallel die plates. Effects of different parameters such as machining method, lubrication condition and deformation percentage on the friction coefficient are investigated with the help of design of experiments and analyzing the results.

Finite element simulation is also used to obtain the calibration curves in the ring compression test. The obtained results reveal the significant effect of die machining process on friction coefficient. In addition, the maximum and the minimum friction coefficient values are associated with the electric discharge machining and grinding with polishing, respectively [21].

Over the past several decades, the growing automotive industry has increased its demand for various parts. In order to meet this demand for parts of various sizes and shapes, conventional processes such as forging, machining and tooling have been used [22].

Among them, cold forging as an efficient process from which dimensionally accurate parts can be made plays an important role. Cold forging can result in components with increased mechanical properties [23]. Although machining, warm and hot forging have been widely used for the forming of industrial automotive parts, cold forging is still a priority choice for manufacturers when it is feasible for practical production.

In the research reported in this paper, it was proposed, by authors, to introduce injection forging as a new forging method to reduce the forging processes in automotive fasteners production, through combining material-flows in a single-stroke forging, such as combining material-flows in the radial and vertical direction as well as forward and backward flows, being enabled by a dicated tool design to realise the process concept with desired material flows. The increased tool stresses may promote crack growth which would reduce tool life. These stresses may also lead to the increased tool deflections, which could influence component accuracy. These issues were addressed in detail in the study reported in this paper with a view to confirming the feasibity of this forging method for the forming of automotive fasteners [24].

Figure 1.3 illustrates a conventional multiprocess forging steps for manufacturing hexagon headed bolts. The billet experiences five deformation steps. Next, the head is backward extruded to form a cavity. The hexagon head is formed and finished in the last two operations.

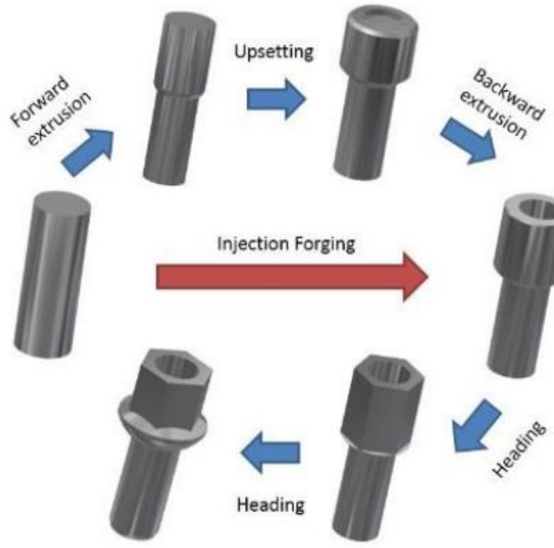


Figure 1.3 Cold Forming Steps

To shorten the process chain, injection forging is proposed. It is intended to combine the first three operations shown in Fig. 1 into one operation. The process concept is shown in Figure 1.4, which uses a floating-die design. The counter-punch is stationery during forming and supports the billet until the final form is achieved. It then moves upwards to eject the part from the die. In this way, the initial billet is formed directly into the intermediate product with a cavity by radial and backwards metal flow.

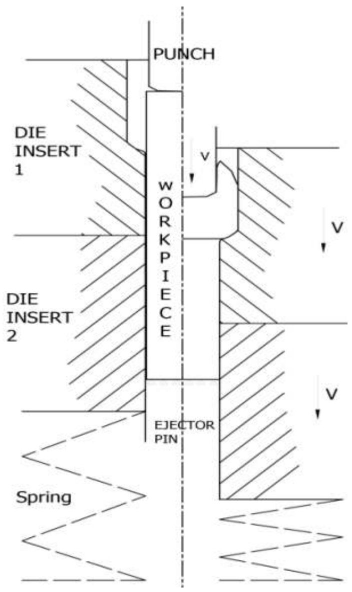


Figure 1.4 Cold Forging Process

In order to investigate the friction in metal forming process, the RCT was used considering its simplicity compared to the other usual tests [21].

The flat surfaces of nserts were machined using one of the following methods:

1. Horizontal milling with HSS1 spiral-tooth cutter (HM)
2. Vertical milling with Tungsten carbide T-max facing cutter (VM)
3. Electrical discharge machining (EDM) with copper cylindrical shape tool (Process parameters: electrolyte: Gas oil, Electrical current: 2A, Pulse on time: 6µs, Pulse off time: 4µs)
4. Grinding (GR) with magnetic surface grinding machine (Process parameters: Grinding wheel speed 1400 rpm, wheel diameter: 300mm)
5. Grinding and finishing (polishing) (GF) (Polishing process was done with sandpapers up to 2000 sandpaper size. Then it was soft polished with a metal polish wax)
6. Turning (TN) with tungsten carbide insert tool.

The insert samples produced by the above methods are shown in Fig. 1.5.

Figure 1.5 The produced inserts with different machining processes

The aim of this research is to qualify an experimental procedure for the fatigue testing of dies under load conditions comparable to real cold forming processes. For this purpose, the test is to be analysed regarding tool life, fatigue cracking and reproducibility compared to results from conventional fatigue tests and industrial forging processes in literature. The results are evaluated in order to identify benefits and challenges compared to conventional fatigue tests.

To enable cyclic testing, the steel workpiece normally used in forging is substituted by an elastomer specimen with the same dimensions as the die bore. Fig 1.6.

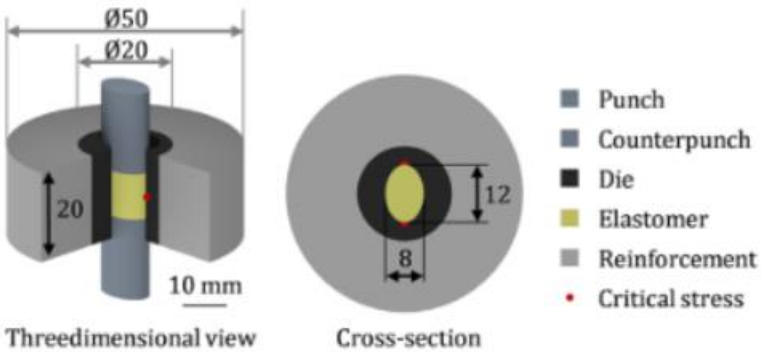


Figure 1.6 Test Setup

The test is implemented as described in section three with the interval for elastomer change determined in section four. This is achieved by exerting a force of 150 kN and defining the corresponding punch position as a reference point. When the punch bottom dead centre decreases by 2 mm triggering an abort criterion, the test is interrupted and a new elastomer specimen inserted into the die in Fig 1.7. [25].

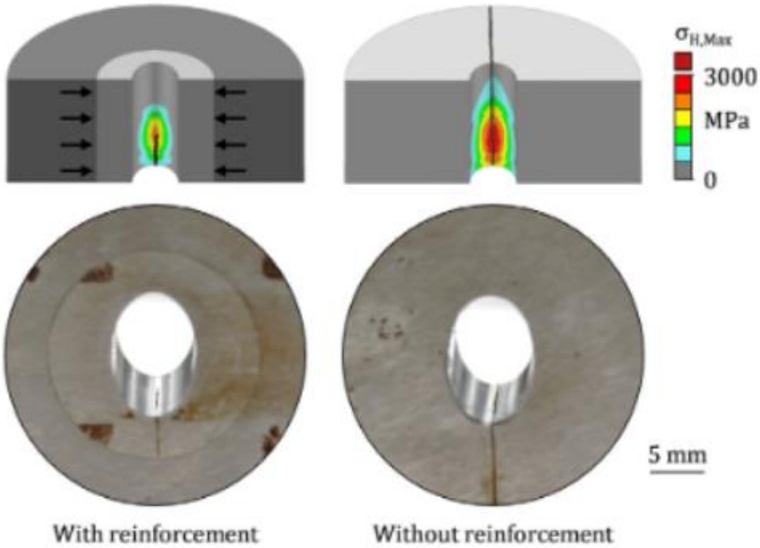


Figure 1.7. Fatigue Cracks in Tested Dies

Fatigue failure in the die is detected via failure of the elastomer specimens. By sudden appearance of a crack in the die, the elastomer has a new opening to flow into under high pressure. Following this, the punch moves downward and the abort criterion defined for elastomer change is triggered. Fig. 1.8 shows a picture of an elastomer after die failure.

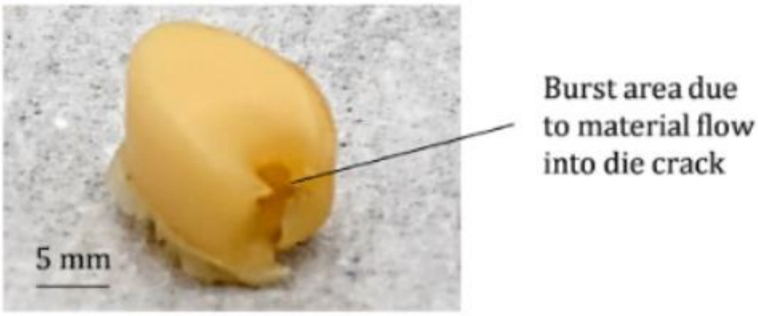


Figure 1.8 Failed Elastomer Specimen After Die Failure

Tungsten carbide (WC) wire drawing dies were taken as workpieces in the present research. WC had a hardness of 8.5–9 on Moh's scale at 22 GPa, a molar mass of 195.86 g/moL with the grey appearance of density 15.8 g/cm3 , a melting point of 2870 ◦C, a boiling point of 6000 ◦C. It was also insoluble in water with a hexagonal crystal structure, according to the information provided by the supplier (Fine Spark, Pune, India). An indigenously developed AFP machine in the laboratory (Figure 1) was used to polish the WC dies. The abrasive media was prepared by mixing boron carbide abrasives with silicon-based polymer and hydrocarbon gel. Whereas the polymer provided necessary stiffness to the media, the gel facilitated the media's smooth movement through the workpiece cavity [26].

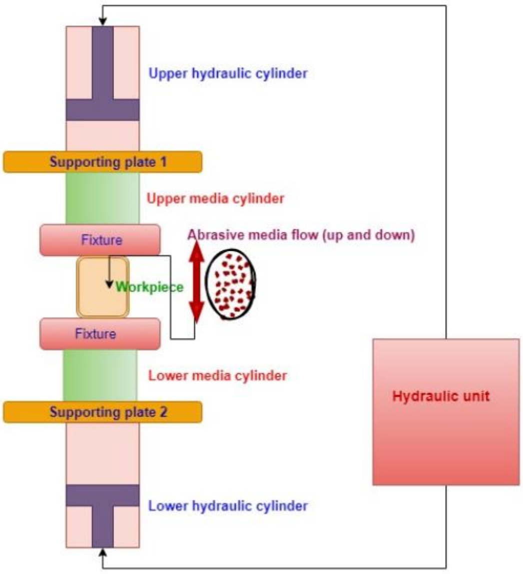


Figure 1.9 Abrasive flow machining set-up

The pictorial view of the special-purpose machine for the hand polishing (HP) of WC wire drawing dies is shown in Figure 2. It consists of a grinding machine, a three-jaw chuck is fastened in place of the grinding wheel to grip the die, and it is rotated at 2800 RPM [27].

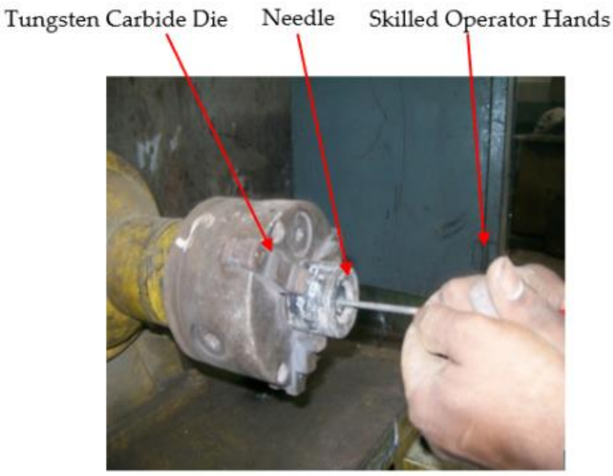


Figure 1.10 Hand polishing of die by the skilled operator

There was a reduced amount of wear and tear of the abrasive flow polished die compared with the hand-polished die [28]. Much of surface is folded metal and not parent metal, so the drawing wire pulls out the folded metal after a short period of use, or dislodges the upper surface of the die [29]. This results in several defects due to the poor surface finish of the die, such as U-shaped cracks, pitting, wear rings, and vertical and horizontal cracks. The rough surface scrapes metal bits off the surface of the steel wire, weakening the lubrication and increasing the wear rate [30].

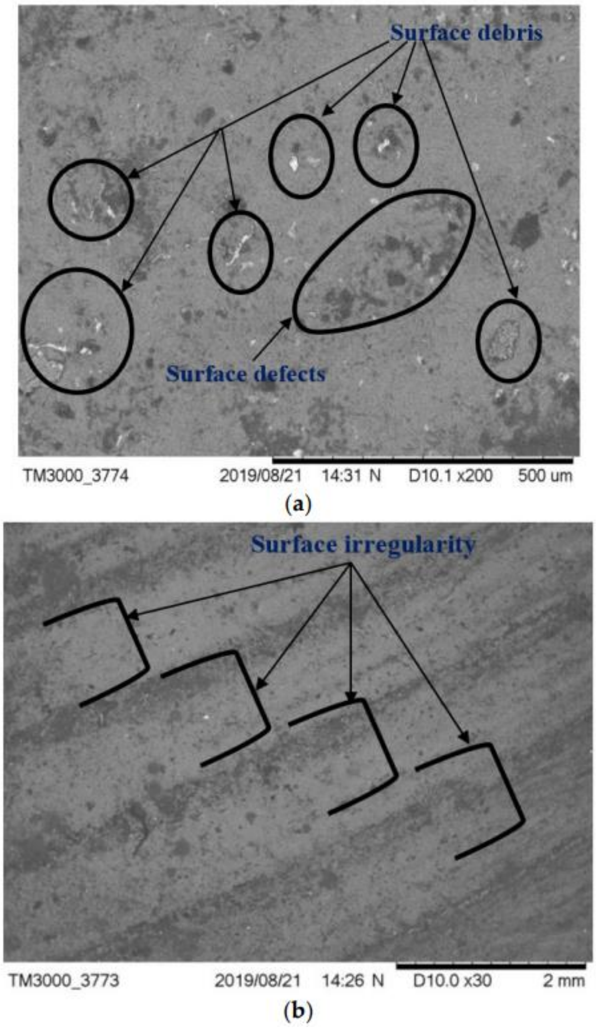


Figure 1.11 SEM micrograph of **(a)** abrasive flow polished die **(b)** hand polished die.

The goal of this thesis study is to upgrade or increase the life of the mold, which is currently working in very low numbers, by making various form and process changes in the segment-cut, flanged nut mold used in the cold forming process in the production of female fasteners, thus minimizing the accidental downtimes experienced in the manufacturer, profitability and efficiency as the mold producing company. to provide added value, to standardize and expand the changes made for other nut molds if sufficient improvements are completed, and to reduce foreign dependency in the supply of nut molds.

2. FASTENERS (NUTS) PRODUCTION PROCESSES

2.1. Tempering

In order for the raw material to be used in the cold forging process to be shaped more easily in the molds in the cold forming presses, the physical properties of the raw material are improved by annealing in the heat treatment furnaces shown in Figure 2.1 [16].

Figure 2.1. Tempering Furnaces

2.2. Surface Treatment

With this process, the surface cleaning and phosphate coating processes of the raw material are carried out in the surface treatment pools as shown in Figure 2.2, allowing the raw material to work easily in cold forging molds. In addition, rusting of the raw material is prevented [16].

Figure 2.2. Surface Treatment

2.3. Wire Drawing

It is the process in which the straightening process is performed as shown in Figure 2.3 in order to obtain a homogeneous surface for the raw material to work comfortably in cold forging machines. In addition, this process prevents the machine from taking a short time (changes in material length) [16].

Figure 2.3. Wire Drawing

2.4. Cold Forging Process

Cold forging is the shaping of metal at room temperature. Nuts, bushings and rivet nuts are produced in cold forging presses with 5, 6 and 7 stations, shown in Figure 2.4, using the cold forging principle [16].

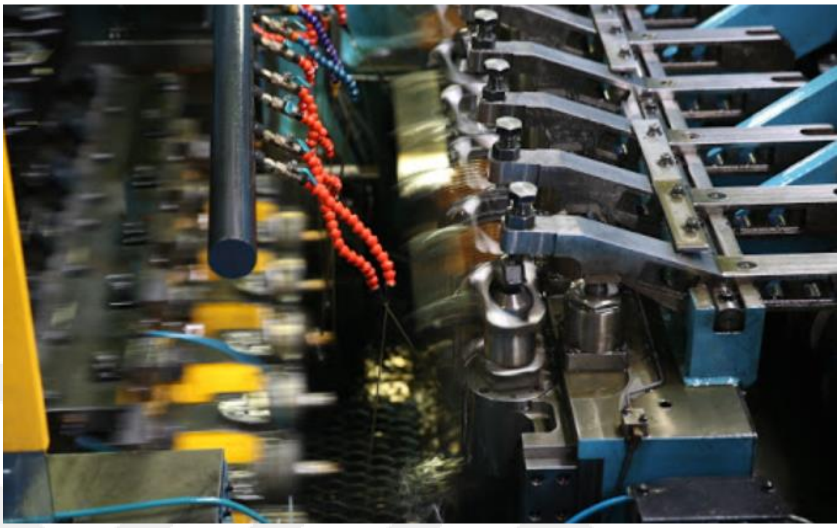


Figure 2.4. Cold Forging Process

2.4.1. Cold Forming Stations

The raw material that will form the nut comes to the 1st station from the coils. Then, it passes to the next station approximately every second and is cold formed at room temperature under high pressure as shown in Figure 2.5.

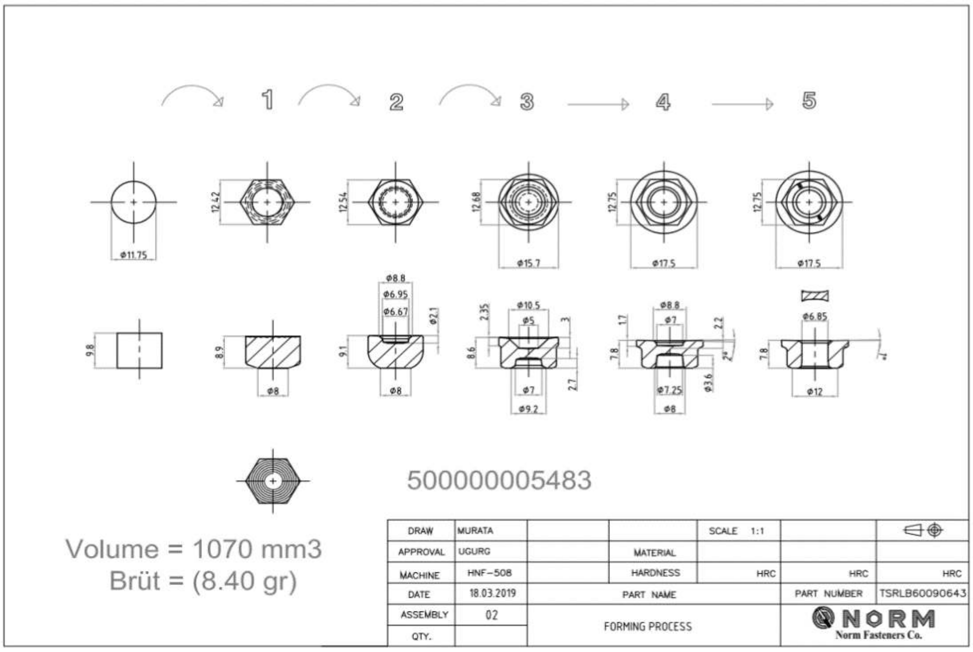


Figure 2.5. Cold Forming Stations

2.4.2. Molds Used in Cold Forming Operations

As shown in Figure 2.6, many nut dies, intermediate dies, punches and ejectors are used together at each station to perform cold forming of nuts.

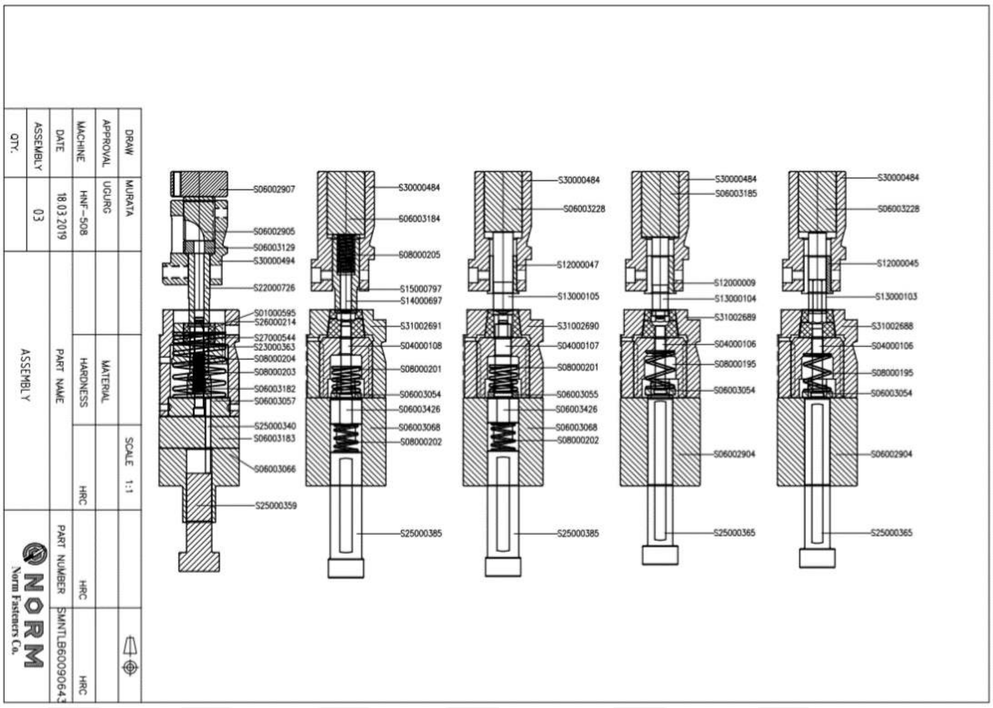


Figure 2.4.2. Molds Used in Cold Forming Operations

2.5. Threading Process

Semi-finished nuts produced as threadless in cold forging machines are threaded with the help of guides in threading machines as in Figure 2.7 [16].

Figure 2.5. Threading Process

2.6. Deburring Process

In order to remove the burrs of the threaded nuts, they are cleaned first with the help of vibration in the vibrator and then with diesel oil in the drum. Then, the nuts are rotated at high speed in the centrifuge machine shown in Figure 2.8 in order to remove the oil used in cold forming and the diesel used in the cleaning process [16].

Figure 2.6. Deburring Process

2.7. Extraction Process

In this process, dimensional and visual control of nuts between M5-M20 and bushings up to Ø20x72 is carried out by computer-controlled nut sorting and bush sorting machines with 5-6-7 cameras, automatic filling and bagging (Figure 2.9) [16].

Figure 2.7. Extraction Process

2.8. Advantages of Cold Forming

In cold forming, it is not necessary to heat the material and dies before forging. A high level of surface quality is achieved and production can be made with low tolerances. Surface oxidation seen in hot forging is not seen in cold forging. The hardness and strength of the material are greatly increased after forging. Thanks to the rapid change of molds and apparatus in cold forging, a small number of products can be produced economically, and program changes in the machines do not take a long time. There is no carbon loss (decarburization) in hot forging.

2.9. Some Cold Forming Methods

2.9.1. Rolling

In this method, the material is passed between two counter rotating mechanisms and crushed. Thus, the material is plastically deformed. The rolling process can be produced in profiles such as rail, U, I, depending on the place to be used, as seen in Figure 2.10. In order to produce different profiles, the mechanism is designed in accordance with the desired profile and calculations are made [17].

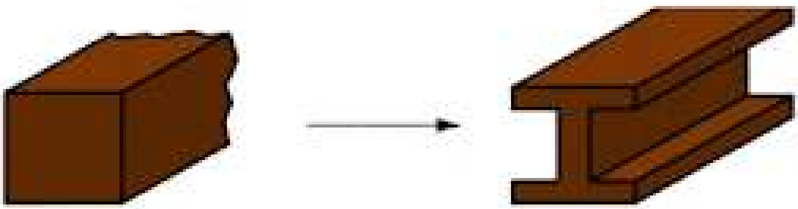


Figure 2.9.1 Rolling

2.9.2. Extrusion

Cold forming as shown in Figure 2.11 by passing the cross-section of the material through a shrinking mold is called extrusion. By applying high pressure to the material, it is ensured that it is brought to the desired cross-section and size. Afterwards, the process is completed by cutting the desired length [17].

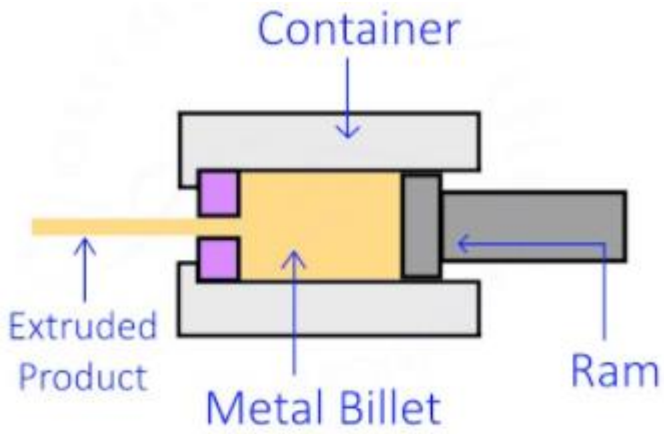


Figure 2.9.2 Extrusion

2.9.3. Forging

Although the forging process is done in different ways, it is generally the process of crushing and shaping between two molds, as in Figure 2.12. It can be applied hot and cold. However, in order to benefit from the advantages of cold forming, forging is applied to small parts when needed [17].

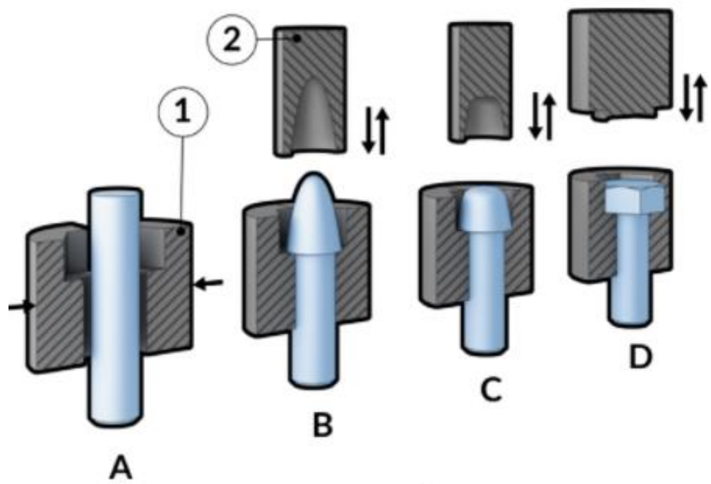


Figure 2.9.3. Forging

2.10. Nut Mold Production Processes

Nut molds are one of the most time-consuming mold types used in the fastener industry, due to the structure shown in Figure 2.13. A punch or pin is produced in about 6-7 operations, a bolt mold in about 10-12 operations, while a nut mold goes through about 20-25 processes.

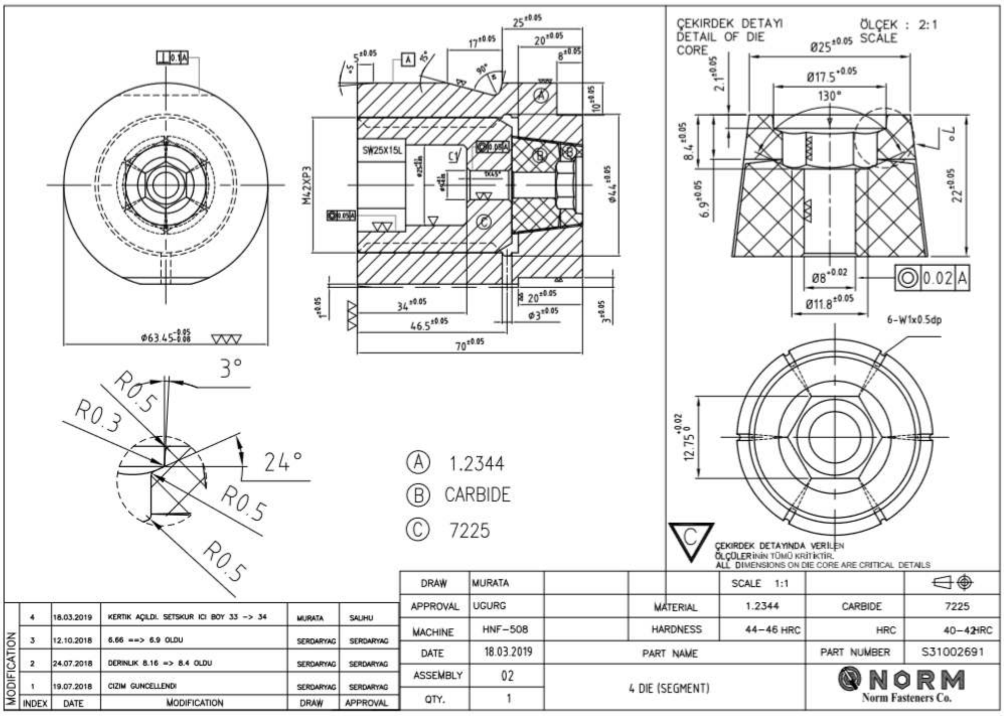


Figure 2.13. Nut Mold Code S31002691

And some of these processes directly affect the life of the mold and play an important role in determining the quality of the mold. In the current situation, the production stages of the nut mold are as follows;

2.10.1. Steel Material Cutting Process

The order pictures that enter the production are first sent to the warehouse, to the saw machines shown in Figure 2.14. Here, the tool steels purchased as long bars by the operator are placed on the bench with the help of a crane, and then the cutting process is performed with a 5 mm margin.

Figure 2.14 Saw Machines

2.10.2. Rough Machining Process to Steel Material Before the Heat Treatment

After the steel materials are cut by saws, they are sent to CNC lathes. The sleeve and rear clamping bolt materials, which have a hardness of approximately 20-24 HRC, are processed in a rough manner with a margin of approximately 0.2 mm from the length, diameter and hole dimensions on CNC lathes as in Figure 2.15 and then sent to heat treatment for hardening.

Figure 2.15 Rough Machined Sleeves and Bolts

2.10.3. Tungsten Carbide Material Cutting Process

While steel materials are cut in saw machines, diamonds, which are the core material of that mold, are also cut in diamond cutting machines as shown in Figure 2.16. This material, which is an alloy containing tungsten carbide – cobalt and has about 2 times higher hardness and strength than steel, is also cut with specially designed bench and cutting wheels.

(a) **(b)**

Figure 2.16 Raw WC-Co (a), WC-Co Cutting Machine (b)

2.10.4. Steel and WC-Co Material Premachining Process

The cut diamond materials and the hardened tool steels from the heat treatment are transmitted to the manual lathes together. Here, steel, which is the outer shell material, and diamond, which is the core material, are processed in a fractional way, as in Figure 2.17, from the length, diameter and hole dimensions.

The diamond material, which will form the core of the nut mold and consists of two parts, the front and the bottom, is sent to the wire erosion machines for the segment cutting process.

Figure 2.17 Lathe Premachining Process

2.10.5. Top Diamond Segment Cutting Process

While the bottom diamond hole, which is cleaned on the lathe, is sent to the grinding benches for processing, the top diamond is sent to the wire erosion department for segment cutting. Incoming top diamond pieces are drawn in the program used for wire erosion workbench and divided into segments as in Figure 2.18. The cutting process in wire erosion is one of the four parameters that directly affect the life of the mold and will be studied within the scope of this project.

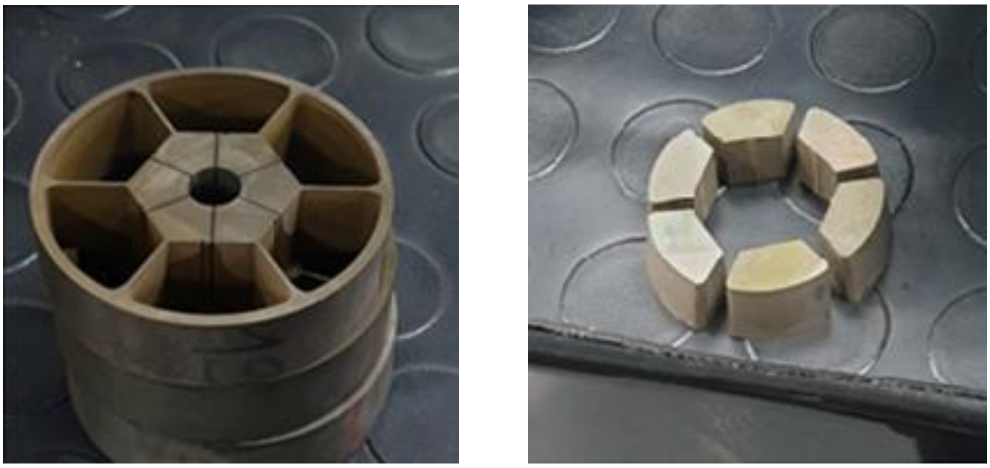


Figure 2.18 Segment Cutting Pieces of Top Diamond

The purpose of the segment cutting process is to absorb the load coming in front of the mold operating under high impact load by opening and closing at micron levels. It is seen that the front diamonds, which are processed in a monolithic way, are broken many times from their sharp corners as in Figure 2.19.

Figure 2.19 Crack Initiation

2.10.6. Shrink Fitting Process

Shrink fitting process is one of the important processes that directly affects the quality of the mold in mold production stages. It is the last operation before the diamond, which is the core material, is mounted inside the outer sleeve made of steel material. It is carried out on cylindrical grinding machines. The outer diameter of the diamond and the bore diameter of the sleeve bore are ground in tight tolerances for good overlapping of the surfaces, as shown in Figure 2.20. Here, the diamond, which is the core material, is processed at a certain rate larger than the hole of the sleeve into which it will pass, in order to ensure tight fit. This ratio is around 0.5%-0.6% in nut molds. For example, if the sleeve hole is Ø40, the outer diameter of the diamond is machined to Ø40,2, giving a firmness value of approximately 0.5%.

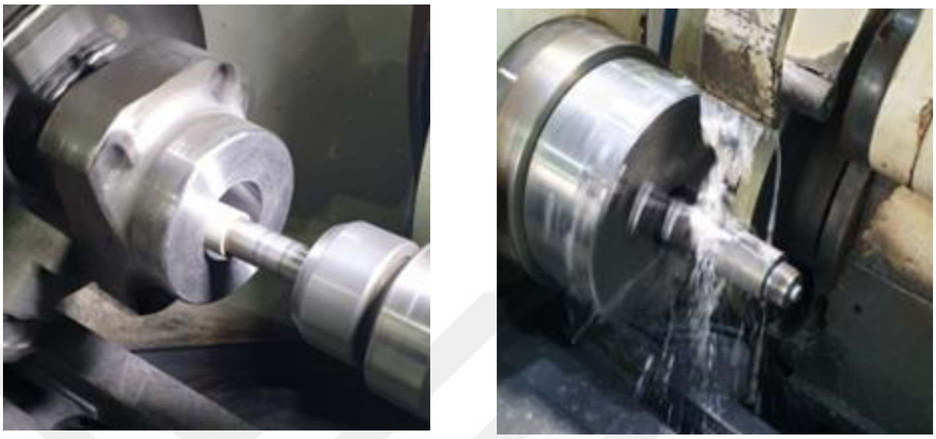


Figure 2.20 Grinding Before the Shrink Fitting

2.10.7. Pressing and Tightening Process

The sleeve and diamonds, which have been tightened and whose contact surfaces have been ground, are mounted coldly in hydraulic presses as in Figure 2.21. Then, the screw bolt shown in Figure 2.22 is tightened to the sleeve from the back of the sleeve so that the diamonds do not come back due to the high impact load applied during cold forming. The bolt, which is tightened from the back of the bucket and rests on the back of the base diamond, prevents the diamond from coming out from the back side due to high compressive stress.

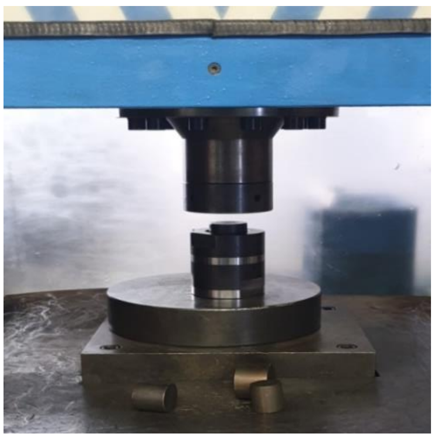


Figure 2.21 Hydraulic Press

Figure 2.22 Set Screw Tightening

2.10.8. Length Completion Process

The molds are sent to the lathe after pressing and squeezing processes. After tightening with a bolt from the back after the press, the diamond part of the mold comes forward a little as in Figure 2.23, therefore the front length cleaning process shown in Figure 2.24 is applied to the mold. Here, together with the chips taken from the forehead, the mold comes to the total length measure.

Figure 2.23 Turning Length Completion Process

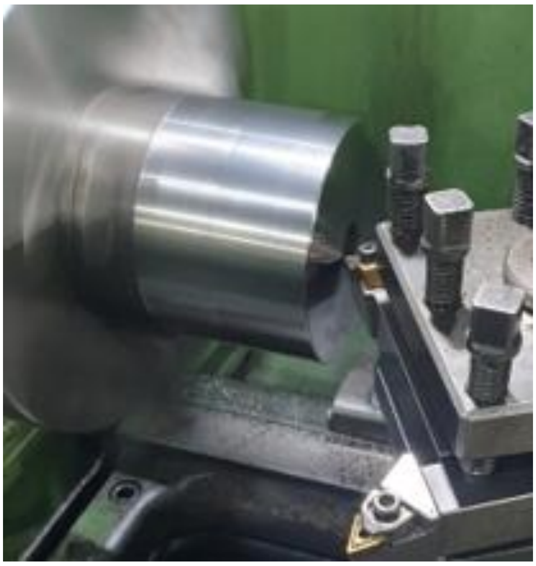


Figure 2.24 Front Diamond Protruding As A Result of Clamping

2.10.9. Copper Electrode Machining Process

The coppers that will form the base form of the nut mold are first processed in a rough form on lathes (a) as shown in Figure 2.25, and then in vertical machining milling machines (b) to reach their final form. A total of 2 or 3 pieces of final copper are used, depending on the size of the mold and the size of the dimensions, as 1 piece for a nut mold.

(a) **(b)**

Figure 2.25 Raw Copper Electrode (a), Finish Electrode (b)

2.10.10. Base Form Machining Process

Prepared coppers are oriented according to the 4 corners of the piece in the plunge erosion section and work by burning with electrical conduction to form the base form of the mold by plunging in the z-axis (Figure 2.26).

Figure 2.26 Base Form Machining Process in Sinker Erosion Machine

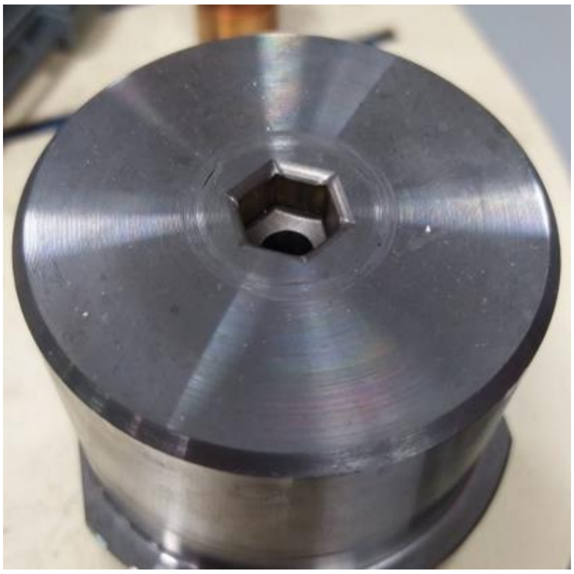


Figure 2.27 Base Form Machined by Copper Electrode

Depending on the diameter and length of the mold, the base form of the part seen in Figure 2.27 is formed after approximately 4-5 hours.

2.10.11. Flange Form Machining

The nut molds, whose base form is processed, are brought to CNC lathes to open the flange form. The nut molds with flange form opened as in Figure 2.28 are ready for the polishing process.

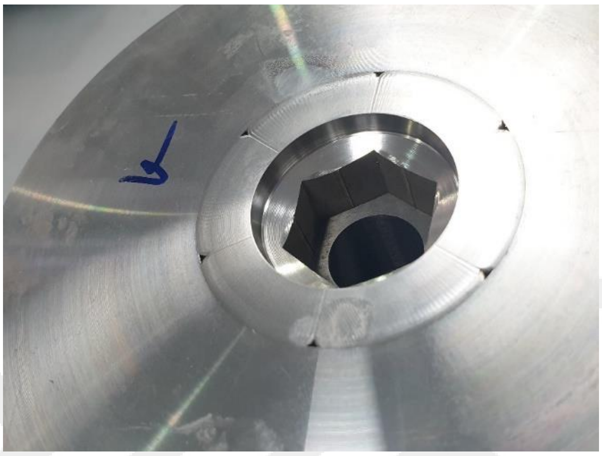


Figure 2.28 Flange Form Machined by CNC Lathes

2.10.12. Polishing Process

The last operation, polishing, is one of the processes that directly affects the life of the mold. Currently, the molds are polished manually by the operators with the help of abrasive paste and wooden sticks as seen in Figure 2.29 (a). Then the mold is ready to be shipped after quality processes (b).

(a) **(b)**

Figure 2.29 Manuel Polishing (a), Polished Final Product (b)

3. MATERIAL AND METHODS

3.1. Material

Nut molds consist of two main components: tungsten carbide cobalt-based core material, which is the general name of "diamond" in the industry, and tool steel as the outer shell.

3.1.1. WC-Co Acquisition and Production Processes

Tungsten carbides; It is produced in 4 main processes: powder preparation, pressing, sintering and final processes. The number of these processes can be increased due to the fact that many final processes can be applied.

3.1.1.1. Preparation of Powders

The manufacture of tungsten carbide begins with the extraction of tungsten ore from the ground. After the first separation and processing steps, pure ammonium para tungstate salt is obtained. Then, with dehydration and separation of the ammonium in the structure, yellow or blue tungsten oxide powder is obtained. Tungsten oxide powder is reduced to pure tungsten powder at temperatures ranging from 800°C to 1000°C. As a result of the cementation process, tungsten carbide (WC) is obtained.

Finally, the desired amount of cobalt is added to the tungsten carbide powder, which has undergone grinding and granulation processes. Lubricants such as paraffin or monoethylene glycol are used to prevent clumping. As a result of the process, tungsten carbide cobalt (WC-Co) powder seen in Figure 3.1 is obtained as the final product [18].

Figure 3.1.1.1 WC-Co Powder

3.1.1.2. Pressing of Powders

The purpose of this process is to obtain a form close to the final form. Pressing takes place at room temperature, under pressure of several tons per square centimeter. Here the powder turns into a monolithic intermediate.

In this procedure, the powder compression dies in Figure 3.2 are used to press the powder. The pressing mechanism consists of a die and upper and lower punch.

Then this intermediate product is processed mechanically (milling, turning, drilling, etc.) and brought to its final form. This method is used to produce flat or cylindrical parts with or without holes. Lubricant (paraffin) is added to the carbide powder and pressed. Before sintering, this paraffin is evaporated in special furnaces [18].

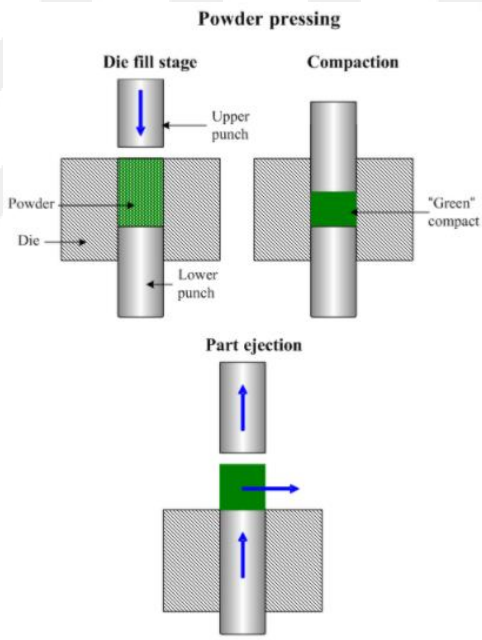


Figure 3.1.1.2. Powder Pressing Die

3.1.1.3. Sintering of Powders

Carbide grades acquire their true properties during the sintering process. The aim is to eliminate the pores and voids in the material and create a homogeneous final product., As a result of the process a homogeneous and dense carbide with high hardness is obtained. In this process, the material is heated to approximately 1300-1500 °C in the special sintering furnaces in Figure 3.3, the cobalt becomes liquid. The structure is intensified with cobalt coating the tungsten carbide grains.

Figure 3.1.1.3. Sintering

Figure 3.1.1.3. Volume Reduction After

As seen in Figure 3.4, the pieces shrink by 20 to 25% depending on the structure and cobalt content. This means that a great deal of expertise is required in the production of semi-finished products so that the final products have the correct dimensions. [18].

3.1.2. WC-Co Material Properties and Internal Structure

Tungsten carbide cobalt (WC-Co) is an alloy consisting of tungsten carbide, a hard phase, and cobalt, a relatively soft and ductile binder phase, shown in Figure 3.5. [18].

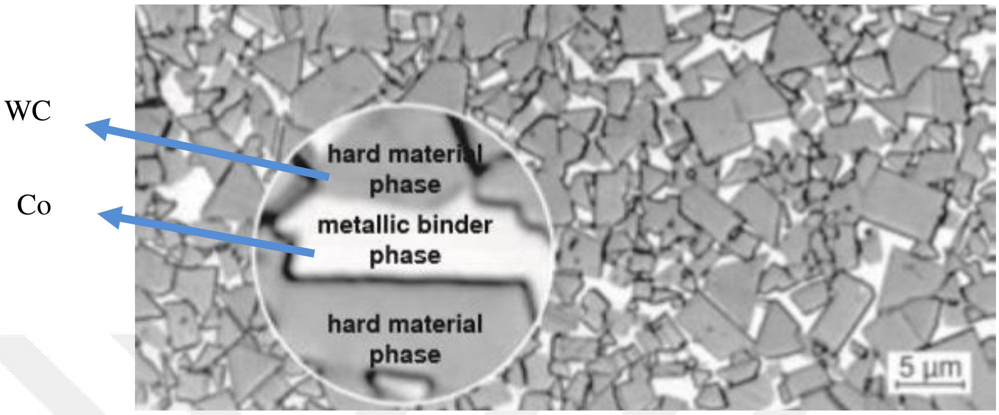


Figure 3.5 WC-Co Internal Structure

Performance characteristics of carbide; The hardness is determined by the transverse breaking strength and fracture toughness. The cobalt ratio and the grain size of the carbide, as shown in Figure 3.6, determine the characteristic of the diamond. [18].

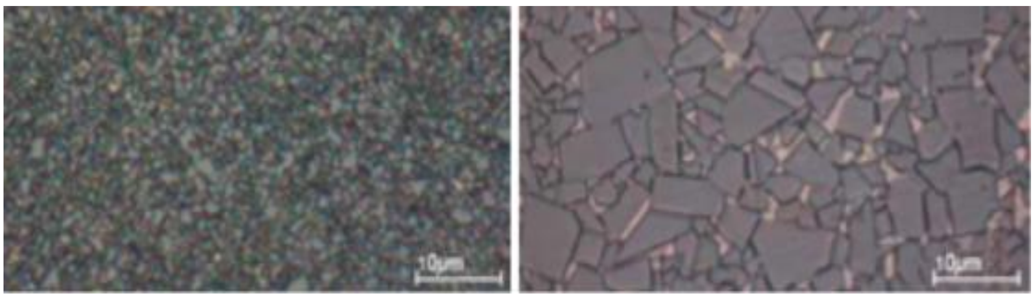


Figure 3.1.2. WC-Co Grain Size Differences

It is seen in the diagram in Figure 3.7 that the hardness of the material increases as the percentage of cobalt in the diamond content decreases. The reduction in the size of the carbide particles has a positive effect on the hardness and transverse rupture strength, while negatively affecting the toughness of the diamond. [18].

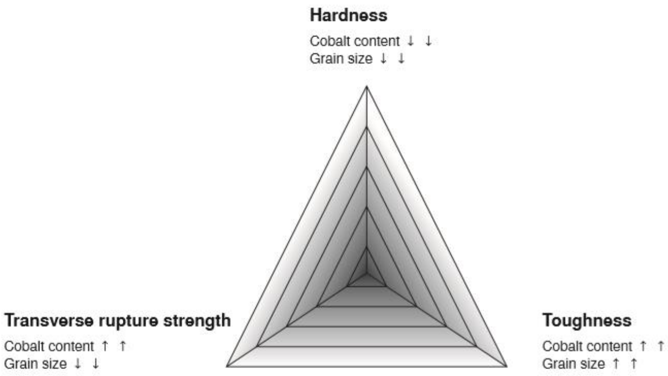


Figure 3.1.2. WC-Co Diagram

3.1.3. EDS Analysis

In the EDS analysis shown in Figure 3.8, Figure 3.9 and Figure 3.10, the elements in the material structure were examined.

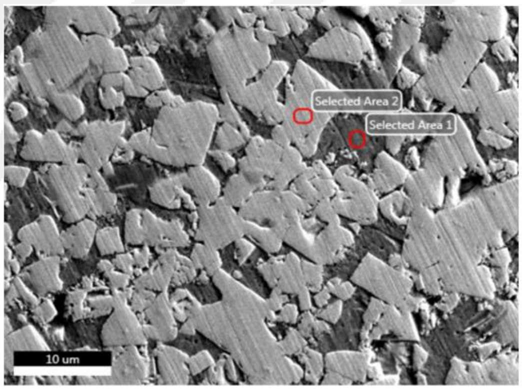
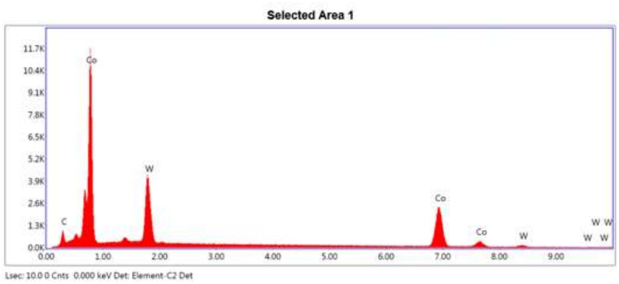


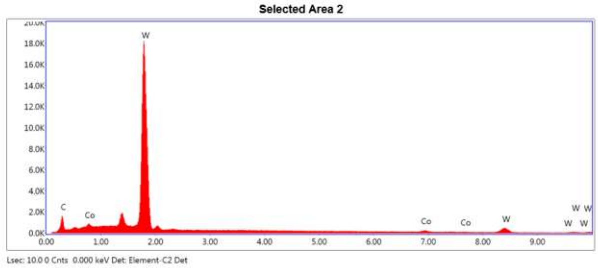
Figure 3.8 Initial Structure



eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	3.36	17.81	232.06	13.07	0.0108	1.4666	0.7896	0.2199	1.0000
W M	30.26	10.48	3059.84	3.64	0.2285	0.8205	1.1868	0.8913	1.0327
CoK	66.38	71.71	3074.92	3.68	0.7189	1.0756	0.9738	0.9847	1.0225

Figure 3.9 Chemical Composition of Area 1



eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	5.75	47.05	512.25	11.61	0.0196	1.7119	0.6921	0.1991	1.0000
W M	92.00	49.19	14787.95	1.99	0.9048	0.9516	1.0413	1.0205	1.0127
CoK	2.25	3.76	147.23	17.35	0.0282	1.2951	0.8989	0.9481	1.0192

Figure 3.10 Chemical Composition of Area 2

3.2. Methods

Within the scope of this thesis, tungsten carbide cobalt-based core material, which is the part where the cold forming process takes place and the damages mostly occur, has been studied.

While choosing the mold code to be worked on, the annual purchasing reports of Norm Holding A.Ş. were analyzed via SAP and the nut mold with the code S31002691 was chosen, which was determined to have a high consumption rate and to be procured abroad, rather than Norm Tooling. While the molds produced by Norm Tooling are damaged at an average of 40,000-50,000 units, the molds of Taiwan companies such as Justice and SanShing are damaged at an average of 600,000 units. It has been deemed appropriate to conduct a thesis on this pattern in order not to smuggle more foreign currency abroad, in an environment with an annual consumption of approximately 140 units, a unit price of $480, and approximately 90% of this order is supplied from abroad.

By making step-by-step improvements on the detected damages and breakage mechanisms, the desired increase in the life of the molds was aimed, and a 4-stage work plan was carried out as follows;

- Changing front diamond type
- Commissioning of radial-formed, carbide-alloyed copper electrode
- Activation of the ultrasonic 5-axis simultaneous grinding method in order to remove the white layers on the surface
- Commissioning of the abrasive flow machining in addition to the manual polishing process

3.2.1.Changing Front Diamond Type

Nut molds contain 2 different types of diamonds as core material, front and base. Currently, CTE35 is used in the base diamond because a higher wear resistance is required in the area where the material will be formed, and in the front diamond, the softer but tougher CTE50 type diamond is used in terms of absorbing successive high impact loads. In Table 3.1, some mechanical properties of CTE50 carbide grades and their values are given.

Table 3.1. Mechanical Properties of CTE 50 Carbide

	Cobalt Content (%)	Density (g/cm^3)	Hardness (HV10)	Fracture Toughness ($MPa*m^{1/2}$)	Compressive Strength (MPa)	Elasticity Module (GPa)
CTE50	25	13,15	760	27	3100	450

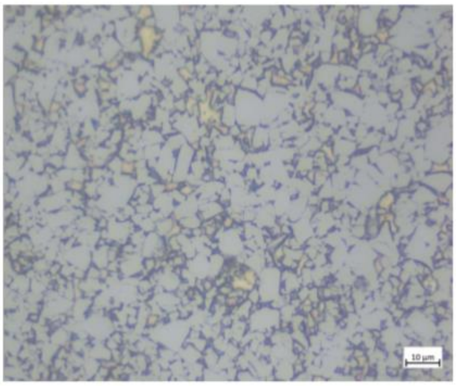
Hardness value of carbides can not be measured by HRC methods because of their high hardness values. CTE 50 carbide’s hardness value is aprx. 65,7 HRC but after that value we have to measure it with the Vickers or Brinell methods.

When the damaged dies were examined, it was observed that the damages generally occurred in the front diamond as seen in Figure 3.11. When the type of damage to the front diamond was examined, it was determined that the damage was caused by nailing from the corners due to wear. The hardness, compressive strength and wear resistance of CTE50 type diamond are lower than CTE35 due to the high amount of cobalt in its structure. Norm Cıvata A.S. After imaging at the Test Center, microstructures with low cobalt content (a) and high cobalt content (b) in Figure 3.12 emerged and it was confirmed that the problem was caused by the diamond type. For this reason, it was thought that the dies were damaged by abrasion from their front diamonds, and for this reason, they worked with a lifetime of approximately 40,000 pieces.

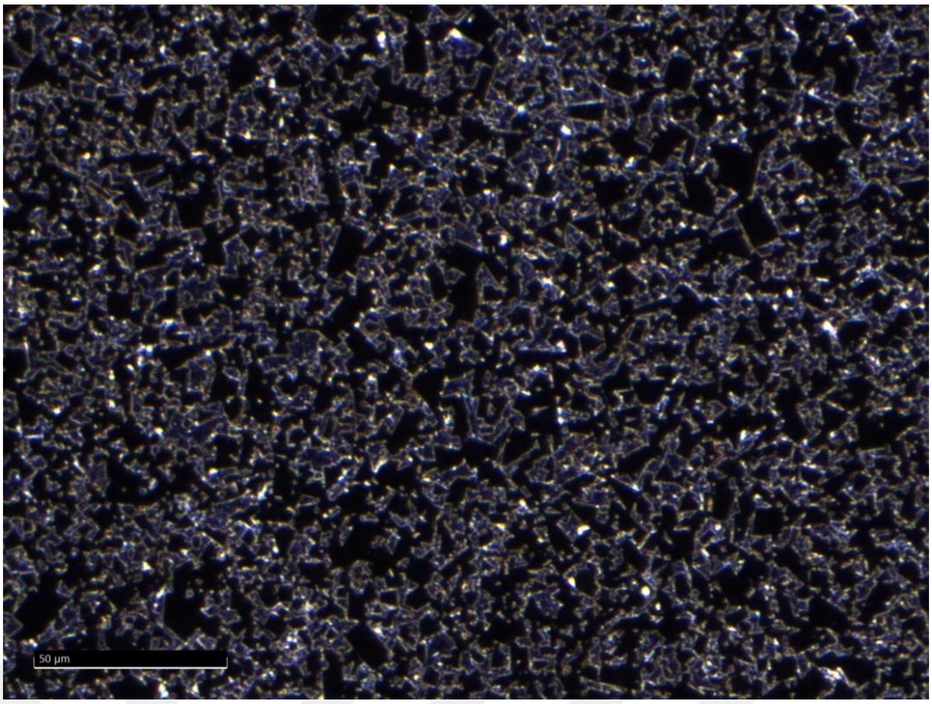
Fracture toughness is the stress that causes a pre-existing crack or defect to grow or propagate. It is an important material property in the manufacturing industry as the presence of imperfections cannot be completely avoided. The stress density factor, which is a function of defect size, geometry, and loading, is used to determine the fracture toughness of a material.

Figure 3.11 Front Diamond Damage

Carl Zeiss Microscopy GmbH



(a)



(b)

Figure 3.12 CTE35 (a) and CTE50 (b) Carbide Type Microstructure

As a result of the analyzes, the type of front diamond was changed, and it was decided to use the CTE35 type diamond, which is used in the sole and is harder, in the front diamond as well. The softer and tougher CTE50 type diamonds were excluded and the newly produced dies were produced with both diamond grades CTE35.

The values of the carbide grain sizes are also shown in Table 3.2.

Table 3.2 Carbide Grain Sizes

Classification of the WC grain size		CERATIZIT code
Average grain size [µm]	Classification	
< 0.2	nano	N
0.2 - < 0.5	ultrafine	U
0.5 - < 0.8	submicron	S
0.8 - < 1.3	fine	F
1.3 - < 2.5	medium	M
2.5 - < 6.0	coarse	C
> 6.0	extra-coarse	E

3.2.2. Design and Commissioning of Radius Formed and, Carbide Alloyed Copper Electrode

The plunging erosion process is frequently used in the production of nut moulds. In this process, copper electrodes with high electrical conductivity, shown in Figure 3.13, are used to form the base form of the mold.

Figure 3.13 Copper Electrodes Formed Base Form

These electrodes, which are connected perpendicularly to the plunging erosion bench, process the material by breaking off pieces from the surface with electrical arc conduction and mold their own form as in Figure 3.14.

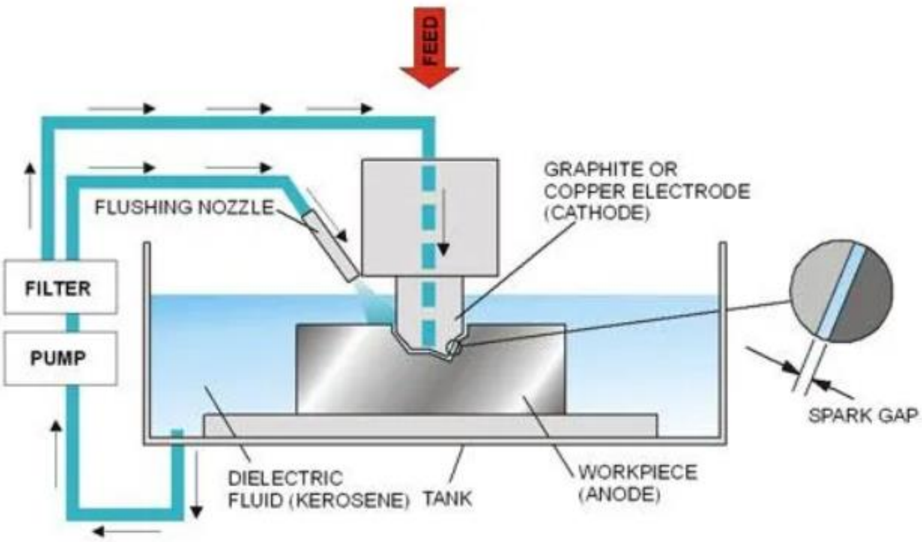


Figure 3.14 Working Principle of Plunging Erosion

The base form of the mold takes its final shape as in Figure 3.15 after it is entered in the plunge erosion benches with copper electrodes that give rough and final dimensions.

Figure 3.15 Nut Mold Base Form Entered

Then, the sharp corners at the mouth of the mold, for which a radius is required, are processed by the operator's hand using a spiral stone as in Figure 3.16.

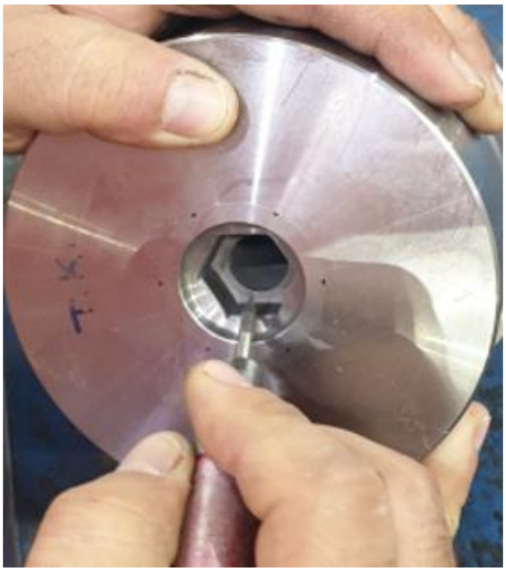


Figure 3.16 Radius Form Machining Process Manually

However, as a result of the processing method performed with this method, the radius at the width across flats of the mold cannot be obtained in the desired form and size, as seen in Figure 3.17. These stone traces negatively affect the material flow during the cold forming process. As a result of pertometer measurements, a chamfer-like surface emerges instead of a radius as in Figure 3.18.

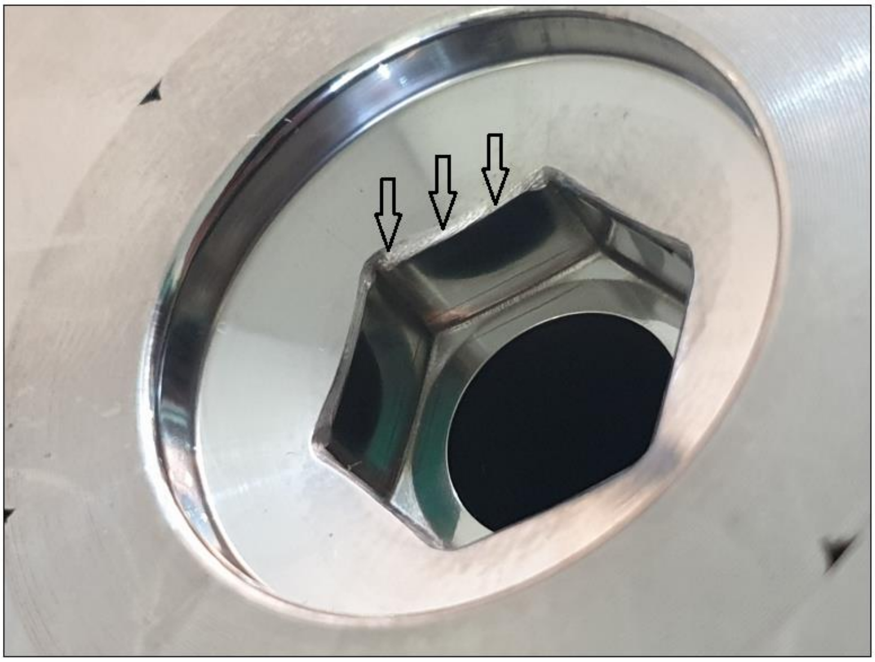


Figure 3.17 Stone Traces

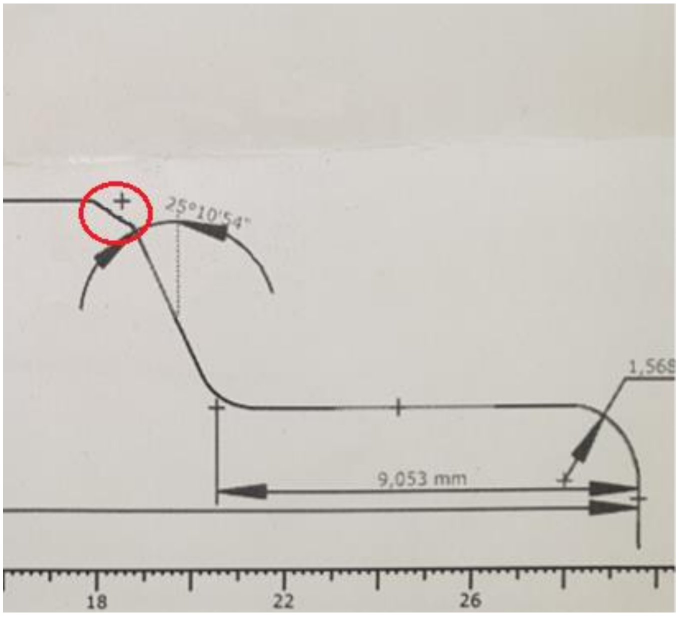


Figure 3.18 Unfit Radius Form

In order to increase the die life, which has been increased to 100,000 - 120,000 pieces in the current situation, it has been studied how this unfit radius form can be processed better as the next improvement. In order for the radius form in the width across flats to appear as desired, the copper electrode design has been changed, and the carbide alloy copper electrode shown in Figure 3.19 has been developed.

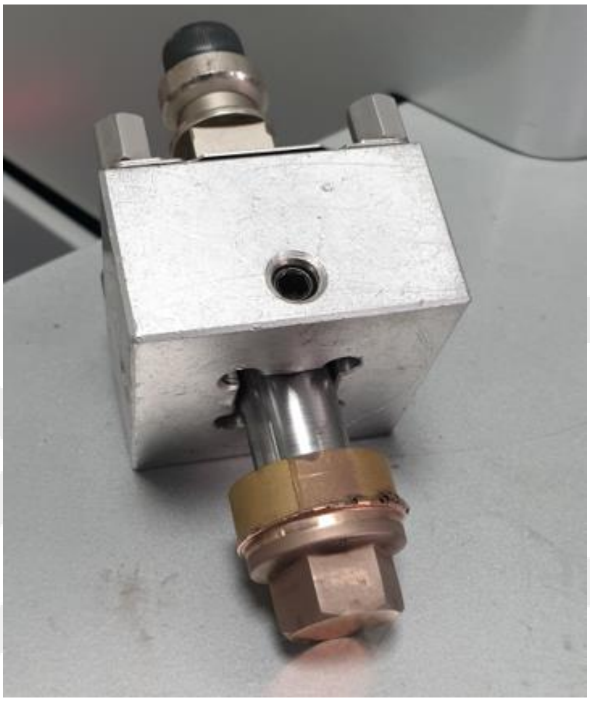


Figure 3.19 Radius Formed, Carbide Alloyed Copper Electrode

Thanks to this developed flange-shaped, carbide-alloyed copper electrode, not only the base form of the mold, but also the flange form and even the brand will be processed, so the desired radius form in the width across flats can be produced in the desired form and dimensions as in Figure 3.20.

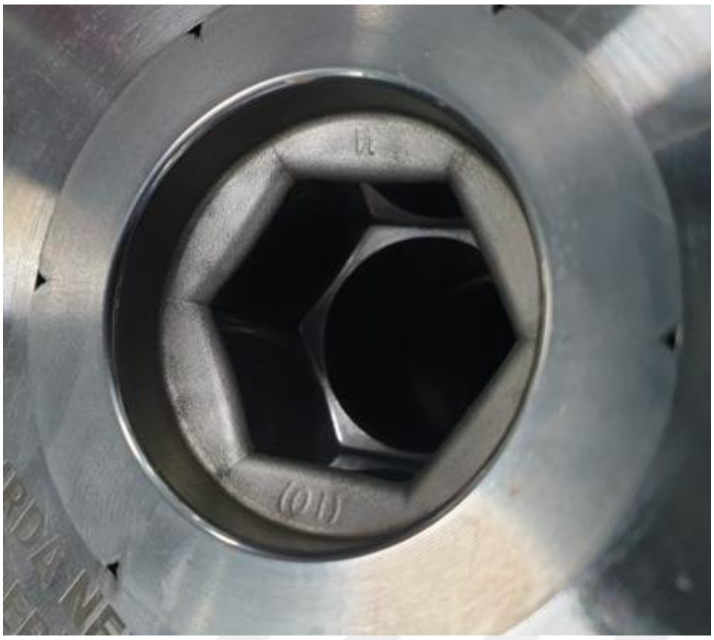


Figure 3.20 Roughly Machined Radius Form

3.2.3. Activation of the Ultrasonic 5-axis Simultaneous Grinding Method in order to remove the White Layers on the Surface

During the diving erosion process with copper electrode, very high amounts of heat (8.000-12.000°C) are released and that temperature drops suddenly with the refrigerant fluid in the system. Due to this rapid cooling, the pieces detached from the copper electrode and the mold material adhere to the surface and form a very hard and brittle structure called the white layer as can be seen in Figure 3.21.

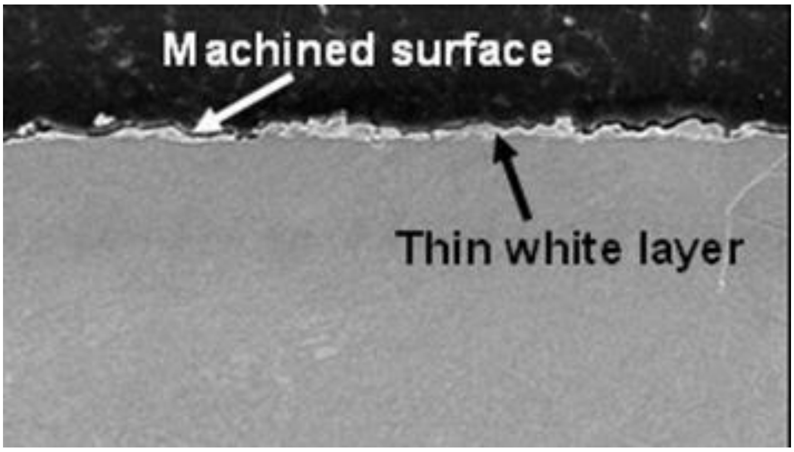


Figure 3.21 White Layer

This brittle structure plays a major role in crack initiation during the cold forming process as can be seen in Figure 3.22.

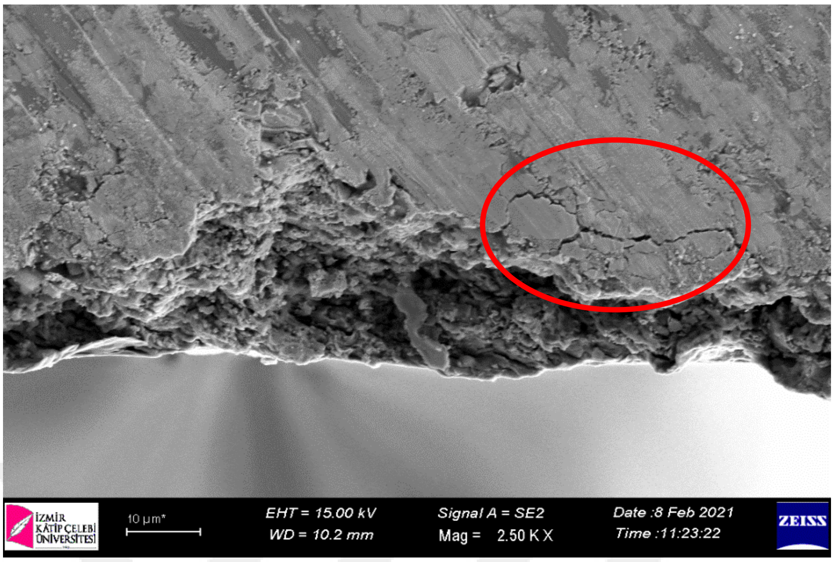


Figure 3.22 Crack Initial

Nut molds were currently being put into direct polishing operation after the erosion process. Because of the polishing operation is a final surface treatment method, the white layer on the surface was not completely removed. A simultaneous grinding process was added between the erosion and polishing processes to completely remove this layer.

3.2.4. Commissioning of the abrasive flow machining in addition to the manual polishing process

The final improvement in the molds was made in the polishing operation. In the current situation, the molds were polished manually by the operator as shown in the Figure 3.23.

Figure 3.23 Manuel Polishing Operation

This kind of polishing was not very efficient and stable since it was in a direction exactly perpendicular to the material flow direction in the cold forming operation.

Abrasiv flow machine was activated in order to have a more evenly distributed polishing process parallel to the material flow direction. In this way, both an equal polishing in all directions and the desired polishing process could be performed at the bottom corners that the operator could not reach by hand.

4. RESULTS AND FINDINGS

4.1. Changing Front Diamond Type

In the current situation, diamond type was used in nut molds with CTE 35 at the bottom and CTE 50 at the front. However, the CTE 50 diamond type was insufficient to withstand the high impact loads in cold forming and was damaged by wear in early cycles.

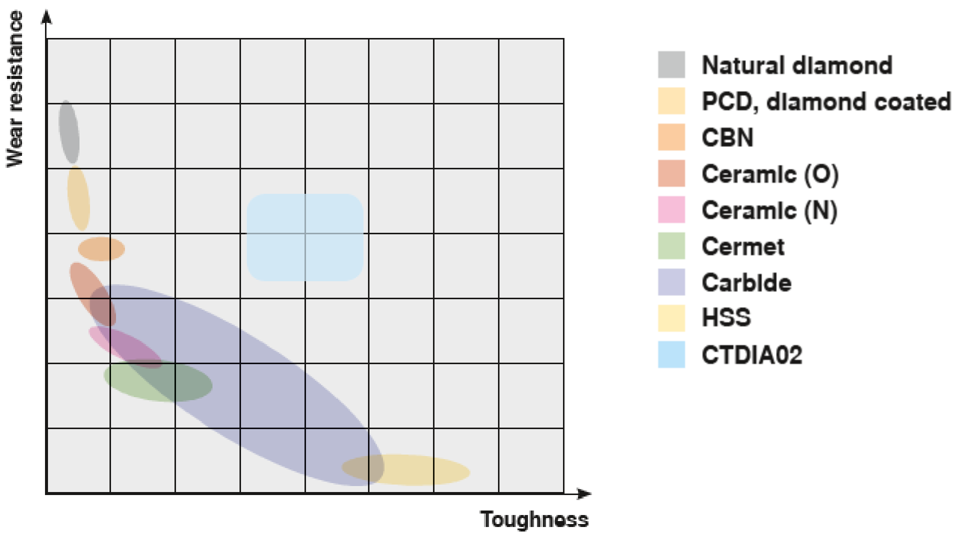
Within the scope of the study, CTE 35 was used instead of CTE 50 in the front apple of the mold. CTE 35 has a higher hardness and wear resistance than CTE50. As seen in Table 4.1.

Table 4.1 Mechanical Properties of CTE 35

	Cobalt Content (%)	Density (g/cm^3)	Hardness (HV10)	Fracture Toughness (MPa*m$^{1/2}$)	Compressive Strength (MPa)	Elasticity Module (GPa)
CTE35	17,5	13,80	910	23	3500	560

Carbides have a very wide working range as in Table 4.2. Desired working conditions can be achieved by making changes in the cobalt percentage and carbide grain size in the structure. In this first phase of the thesis, a higher wear resistance was aimed by choosing a carbide with a lower cobalt ratio.

Table 4.2 Materials Properties Range



3 trial dies were produced with the traditional method, and then 3 more trial dies were produced with new diamonds. The number of work seen in Table 4.3 was observed.

Table 4.3 First Changes of Life Cycle of the Nut Molds

Traditional	New
38.000	102.000
45.000	98.000
39.000	107.000

4.2. Design and Commissioning of Radius Formed and, Carbide Alloyed Copper Electrode

The most common damage mechanism in nut molds occurs at the across witdh of the molds due to unsuitable radius forms. As a result of the operator's manual processing of the key blade, the mold does not form in the desired form. In the cold forging simulation, it is seen that there is a stress above the strength limit of the diamond in the radius regions of the die (Figure 4.1).

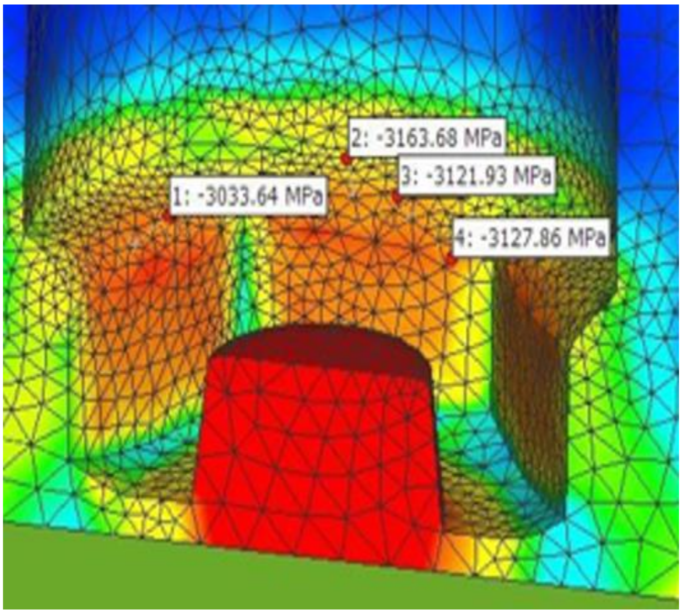


Figure 4.1. Cold Forming Simulation Before the Changing of Carbides

As seen in Table 4.1, the compressive strength of CTE 35 diamond is 3500 MPa. In the simulation, it has been seen that these values are very close and the strength conditions of the diamond are very difficult.

A major overhaul of the machining of the die radius has been made to avoid this critical stress. and in this context, the copper electrode design used in the plunge erosion process was changed. The electrode design in Figure 4.2 was developed in the Solidworks program.

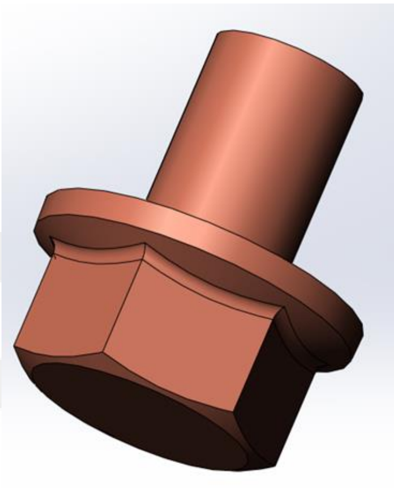


Figure 4.2 Carbide Alloyed and Radius Formed Copper Electrode CAD Model

The new design seen in Figure 4.3 has a radius form and also a carbide alloy in copper.

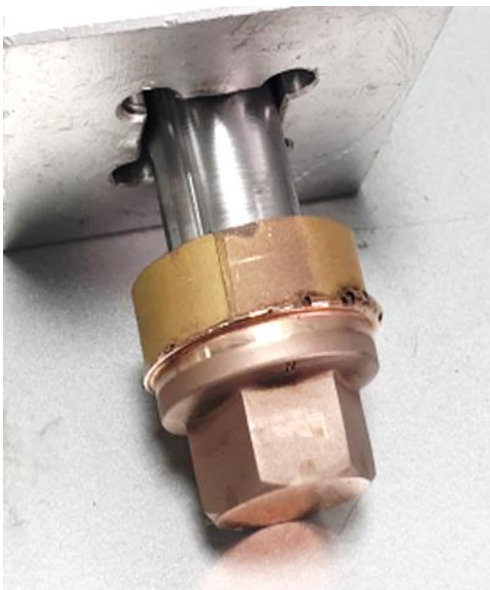


Figure 4.3 Carbide Alloyed and Radius Formed Copper Electrode

The radius form of the molds produced with the new method came out in the desired dimensions.(Figure 4.4, Figure 4.5)

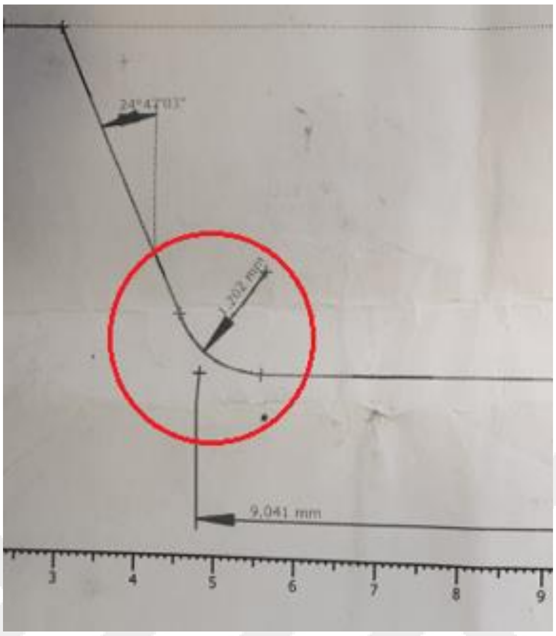


Figure 4.4 Radius Form Meausurement on Pertometer

In the cold forging simulations made, it is seen in Fig. 4.6 that the compressive stresses formed in the across width have decreased significantly.

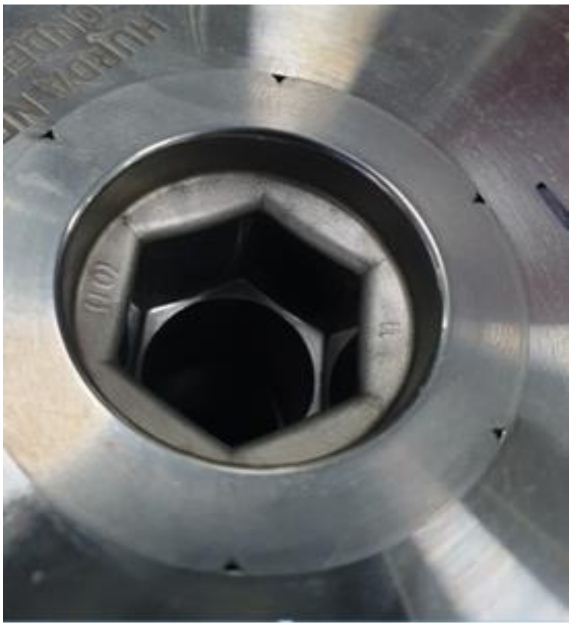


Figure 4.5 Proper Radius Form

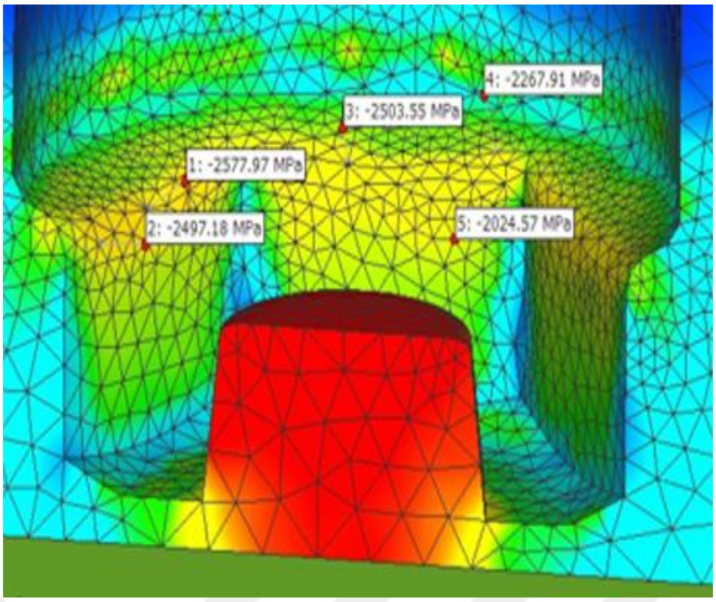


Figure 4.6 Cold Forming Simulation Before the Changing of Carbides

After the improvement, 3 pieces of the molds were produced and tested in the cold forming process. The compressive stresses seen in the radius part of the mold were reduced by approximately 24%. As can be seen in Table 4.4, there has been aprx. 4 times increase in die life.

Table 4.4 Second Changes of Life Cycle of the Nut Molds

Traditional	New
98.000	447.000
102.000	402.000
107.000	413.000

In this simulation, tetrahedral (134) element type, 1.00814 element size and 1.30 coarsening factor are used for base carbide. 0,699324 element size for one segment piece of front carbide and 4.0 element size for the outer ring of the die are used for. Mesh independence was checked with 3 different mesh parameters and 98% accuracy was observed.

On the other hand, tetrahedral (247) and 0,590774 element size values are used for the workpiece as Simufact simulation mesh parameters.

4.3. Activation of the Ultrasonic 5-Axis Simultaneous Grinding Method in order to remove the White Layers on the Surface

Simultaneous grinding method was included in the production process in order to remove the white layer formed after the diving erosion process.

This special 5-axis grinding machine in Figure 4.7, which is not normally used for grinding nut molds, was commissioned within the scope of the thesis.

Figure 4.7 DMG Mori 5-Axis Ultrasonic Simultaneous Grinding Machine

The grinding process was done on a special processing machine with 5 axes and special griniding tool a seen in the Figure 4.8, the white layer on the surface was completely removed as seen in the Figure 4.9 and the mold was transferred to the polishing process in that way.

Figure 4.8 Special Grinding Tool

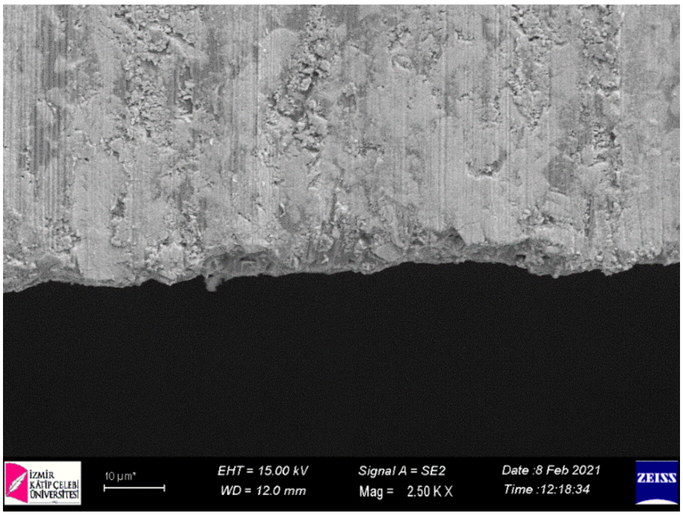


Figure 4.9 Removed White Layer

Potential crack initiation risks are also eliminated thanks to the brittle white layer removed from the surface. In the molds produced with the new method, the life increases seen in Table 4.5 were observed.

Table 4.5 Third Life Cycle Increase After the Improvement

Traditional	New
447.000	607.000
402.000	620.000
413.000	602.000

4.4. Commissioning of the Abrasive Flow Machining in Addition to the Manual Polishing Process

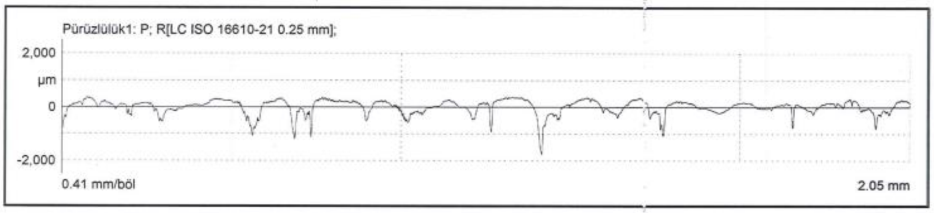
Changed the polishing process method for a final improvement of the mold after grinding operation.

Polishing process was made manually by the operator's hand skill with the chopstick and the abrasive paste as mentioned in Chapter 3.2.4. The entire surface of the molds could not be polished evenly due to the manual process. Since it is extremely important that the surface roughness of the molds is low values in terms of a proper cold forming process, a change was made in this process.

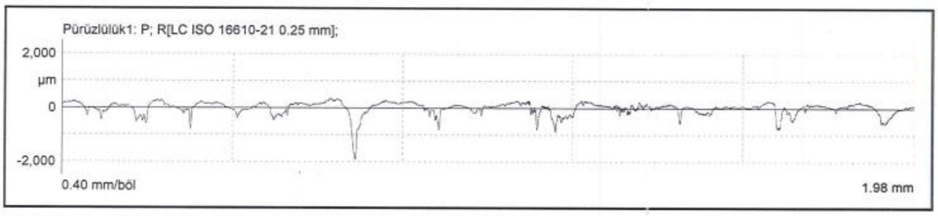
The Ra values of the molds produced by the current method were as in Table 4.6.

Table 4.6 Ra Values Before the Polishing Process Improvement

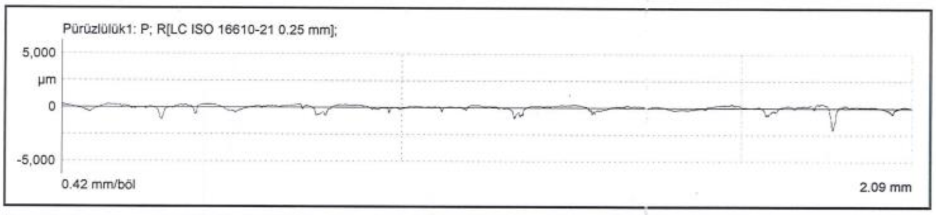
Die Number	Ra Values
1	0,199 µm
2	0,158 µm
3	0,166 µm



Pürüzlülük parametreleri - Pürüzlülük1: P; R[LC ISO 16610-21 0.25 mm];						
Ra	0,1999 µm	0,0000				0,0000
Rz	1,4920 µm	0,0000				0,0000
Rmax	2,1441 µm	0,0000				0,0000



Pürüzlülük parametreleri - Pürüzlülük1: P; R[LC ISO 16610-21 0.25 mm];						
Ra	0,1580 µm	0,0000				0,0000
Rz	1,2893 µm	0,0000				0,0000
Rmax	2,2758 µm	0,0000				0,0000



Pürüzlülük parametreleri - Pürüzlülük1: P; R[LC ISO 16610-21 0.25 mm];						
Ra	0,1663 µm	0,0000				0,0000
Rz	1,4149 µm	0,0000				0,0000
Rmax	2,4421 µm	0,0000				0,0000

With the commissioning of the abrasive flow machine in Figure 4.10, a much more stable and evenly distributed polishing process was applied in the mold.

Figure 4.10 Extrude Hone Abrasive Flow Machine

AFM machine works with the principle that abrasive pastes move up and down as seen in Figure 4.11 in the mold under high pressure like 150 bar. Ra values in the nut molds produced with the new method were observed as in table 4.7.

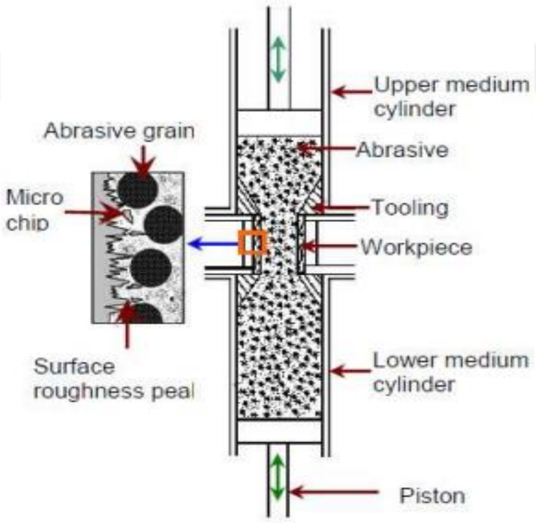
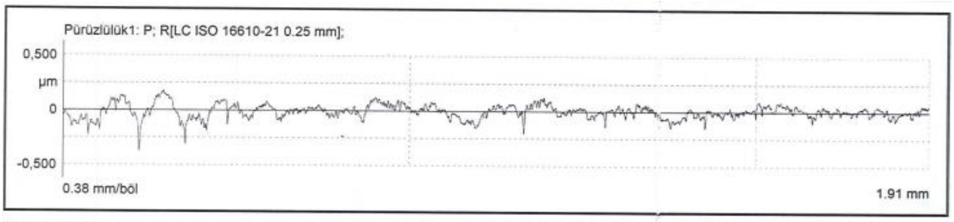


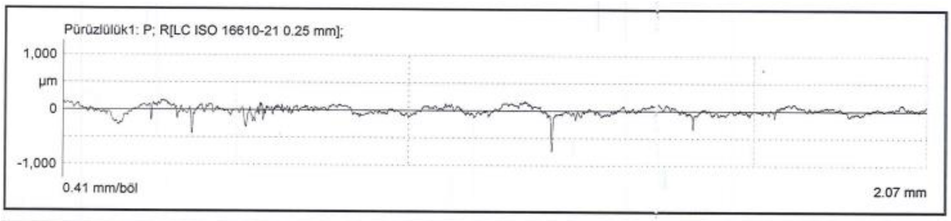
Figure 4.11 AFM Working Principle

Table 4.7 Ra Values Before the Polishing Process Improvement

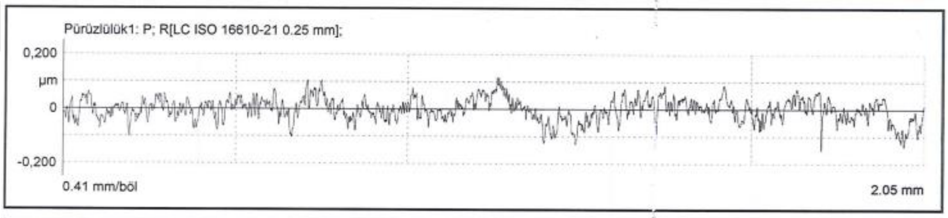
Die Number	Ra Values
1	0,047 µm
2	0,056 µm
3	0,031 µm



Pürüzlülük parametreleri - Pürüzlülük1: P; R[LC ISO 16610-21 0.25 mm];						
Ra	0,0474 µm	0,0000				0,0000
Rz	0,3091 µm	0,0000				0,0000
Rmax	0,5529 µm	0,0000				0,0000



Pürüzlülük parametreleri - Pürüzlülük1: P; R[LC ISO 16610-21 0.25 mm];						
Ra	0,0568 µm	0,0000				0,0000
Rz	0,5418 µm	0,0000				0,0000
Rmax	0,9187 µm	0,0000				0,0000



Pürüzlülük parametreleri - Pürüzlülük1: P; R[LC ISO 16610-21 0.25 mm];						
Ra	0,0318 µm	0,0000				0,0000
Rz	0,2038 µm	0,0000				0,0000
Rmax	0,2454 µm	0,0000				0,0000

When the molds produced with this method in the polishing process were tested in the cold forming process, the lifetime increases in table 4.8 were observed.

Table 4.8 Fourth and Last Life Cycles After the Improvement

Traditional	New
607.000	660.000
620.000	685.000
602.000	645.000

5. SUMMARY AND SUGGESTIONS

Within the scope of the thesis, the nut mold used in the cold forming process during the production of fasteners was examined.

Every mold has a certain working life and every die will eventually break. The important thing here is to get the maximum efficiency that can be obtained from a mold and not to interrupt the serial production in the cold forming process.

In this study, it was concluded that how effective the carbide types used in the molds are on the life of the mold. It has been observed that using tougher carbides with low hardness as a precaution against impact loads does not always give very effective results. In the scope of the thesis, it is aimed to increase the wear resistance by using a harder carbide in the front diamond, just as it is used in the base diamond. And switching to a less tough but harder carbide in the pre-diamond type resulted in an approximately 2 times increase in die life.

Secondly, the part of the nut forming the across width and flange connection was studied in the mold. It was concluded that the quality of the radius form there directly affects the material flow in the cold forming operation.

The reason for the formation of the distorted radius form in the molds produced by the traditional method was examined and simulations were made. A radical change was then made in the form and material of the copper electrode used in the plunge erosion process to create a more proper radius form. Simulation studies were also carried out for the molds produced with the new method and the molds were tested in serial production. A 4-time increase in life was observed in the molds. With this result, it has been seen that one of the most important factors in the quality of a nut mold is the radius on the flange and its smoothness.

Then, more detailed studies were started in order to provide an even better life increase in the mold. After the plunge erosion process, the mold surfaces were examined and here were found important findings that will negatively affect the working life of the mold. Removal of the white layer is very important for increasing the life of the nut molds. With the previous significant improvement, it has already been observed that the life of the nut mold has increased a lot after the white layer of the nut mold has been removed.

Finally, the polishing process, which is the last process of mold production, has been studied. Instead of manual polishing operation, an automatic polishing process in which pressurized fluid is used has been switched. While a polishing operation was carried out against the flow direction of the material in cold forming, a polishing method parallel to the material flow direction in the mold was started with this improvement.

With these radical changes, the die life has been increased from around 40,000 on average to around 650,000 on average. In addition, the holding's need for this mold has been shifted from the Far East companies to the existing company of the holding and a national added value has been provided.

While the company sold a total of 7 pieces of this mold last year, the annual sales of molds increased to 25 after this development. The annual turnover increased from 3.360 $ to 12.000 $. Also, one die cost of the dies produced by the traditional method was $336. The firm was selling them for around $480 with a 30% profitability.

With these improvements and process steps reductions, the cost of a mold has dropped to around $280 with the depreciation cost. As a result, the unit profitability rate per die increased from 30% to 42%.

For the next year, it is aimed to sell approximately 48-50 molds and a turnover of around 23.040 $ - 24.000 $ for the mold coded S31002691.

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