Journal of Materials and Electronic Devices 1 (2024) 13-18

JOURNAL OF MATERIALS AND ELECTRONIC DEVICES
FYTRONIX JMED http://dergi-fytronix.com/

Extrusion Die Design and Production from Inconel 718 Superalloy Material

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In this study, extrusion mold design and manufacturing were examined using Inconel 718 superalloy material to address critical issues in the production process. The aim was to prevent production disruptions caused by thermal fatigue, hot tearing, thermal shock, abrasion, and other mechanical deformations. The use of a material with advanced mechanical properties was targeted for this purpose. Inconel 718 and hot work tool steel were compared, evaluating chemical composition, surface roughness, and conductivity. It was concluded that Inconel 718, with its higher Cr content, superior mechanical properties, and similar conductivity values, provides advantages in the production process.

Keywords: *Extrusion die, Inconel 718, Mechanical Properties , Super alloy*

Submission Date: 02 January 2024
Acceptance Date: 06 March 2024

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1. Introduction

Hot work tool steels; it is a steel group preferred in many industrial areas due to its ability to maintain its abrasion and rupture strength values at high temperatures, its high toughness values, and its high impact resistance at high temperatures [1-4].
Today, hot work tool steels are used in many high temperature applications such as injection and extrusion [5,6]. Due to the need in usage areas; hot work tool steels must have very high wear resistance and carry the load they are subjected to without plastic deformation, which is directly related to the hardness of the steel [7]. The increase in hardness leads to a decrease in ductility and the maximum hardness value after heat treatment is the most important criterion in choosing the right process [8,9]. The features that all tools used in hot work applications should have can be listed as follows [10];

- Resistance to deformation at application temperatures,
- Resistance to mechanical and thermal shocks,
- High temperature wear resistance,
- Resistance to heat treatment deformations,
- Workability,
- Resistance to hot tearing.

Defects such as cracking, breaking, scratching or sticking of the product to the mold occur in the molds due to thermal fatigue, hot tearing, thermal shock, abrasions on the tool-part contact surface, local overloads or other mechanical deformations seen in some extrusion molds during use [11,12]. Of these defects, the most common mechanical crack propagation; it occurs due to thermal (hot) fatigue that occurs when surface cracks come to a reticulated structure [13]. In applications where hot work tool steels are used, for example, metal injection and extrusion, thermal fatigue is a damage caused by the nature of the process and causes stress damage due to thermal expansion due to the heat gradient on the die surface after repeated thermal cycles
Thermal fatigue is a damage mechanism that limits die life in metal injection, forging and extrusion applications [14,15]. Due to these damage mechanisms, alternative materials have been researched.
Inconel 718 is expressed by the term "superalloys" be-cause of its long-term successful applications at high tem-peratures

[16]. Superalloys are used in industrial gas turbines, spacecraft, rocket engines, nuclear reactors, submarines, steam generating plants, petrochemical devices, glass industry, hot tools and other heat resistant applications [17,18].

Inconel 718 superalloy is an age-hardenable nickel-chromium alloy [19]. Inconel 718 (IN718) is recognized as a nickel-based superalloy of choice in critical components due to its high friction resistance, high temperature re-sistance, oxidation resistance and hot corrosion resistance. [20,21,22].

Thanks to the superior properties of Inconel 718 super alloy, extrusion molds are produced that are resistant to thermal fatigue, abrasion and mechanical stress for a longer time in high temperature applications. In the study, molds in three different models (10x120, 5x100, 10x80) were designed and molds were manufactured from Inconel 718 material.

2. Material and Methods

2.1. Chemical compositions of alloys

The chemical compositions and values (%) of X38CrMoV5-3 (1.2367) [23] hot work tool steel and Inconel 718 [24] superalloy are given in Table 1.

Tab.1. Chemical compositions of X38CrMoV5-3 (1.2367) hot work tool steel and Inconel 718 superalloy.

	Alloys	
Elements wt. %	Inconel 718	X38CrMoV5-3 (1.2367)
Al	0.70	
Cr	21	5.00
Co	1	
Cu	0.3	
Fe	Balance	
Mn	0.35	
Mo	2.80–3.30	3.00
Ni	50–55	
Nb + Ta	4.75–5.50	
Si	0.15	
Ti	1.15	
C		0.38
V		0.50

When we examine the chemical compositions and values of the alloys in Table 1, the Cr amount in the X38CrMoV5-3 (1.2367) alloy is 5.00, while it has a value of 21 in the Inconel 718 alloy. Cr; it increases hardenability, corrosion-oxidation resistance and high temperature resistance [25]. With the use of Mo as an alloying element, a fine-grained structure is obtained, while fatigue strength and hardenability increase. In stainless steels, it provides corrosion resistance with Ni and Cr and reduces the steel's susceptibility to pitting. In the study conducted by Wang (2006), it was determined that the wear property at high temperatures increased significantly with the increase of the Cr content of the material from 3% to 4%, and the Mo content from 2% to 3% [26]. When we examine the distribution of chemical compositions in general, Inconel 718 alloy has been chosen as an alternative material to produce extrusion molds that are resistant to thermal fa-tigue, wear and mechanical stresses in high temperature applications.

2.2. Extrusion die design

3D and 2D mold designs were carried out using the 3D design program (AUTOCAD). During the mold design, molds with the dimensions of 10x120mm, which we had the most problems with and had a higher deformation rate, were manu-factured. These parameters are mold material properties, mold dimensions and mechanical processing (turning, milling, wire erosion) methods. An extrusion mold used to manufacture the products having rectangle cross-section (Fig 1).

Fig.1. 10x120mm Inconel 718 mold visual display.

2.3. Connecting the mold

The molds produced are placed in the material called the hive. Thus, it reduces the deformation rate of the existing mold. Mold shells are placed in reheat furnaces with 500°C for 4 hours and subjected to heating process. This is be-cause the material is more comfortable to draw when the mold is hot. The connection of the die to the extruder is shown in Fig 2.

Fig.2. Visual demonstration of connecting the mold to the extruder.

2.4. Surface roughness measuring device feature

Mahr brand Marsurf PS1 device, a portable surface roughness device, was used to measure surface roughness (Ra) values in order to determine the surface quality of the final materials coming out of the extrusion die made of X38CrMoV5-3 (1.2367) hot work tool steel and Inconel 718 super alloy (Table 2).

Tab.2. Surface Roughness measuring device feature.

MODEL	Mahr (MarSurf PSI)
Measuring Method	Follower tip (stylus) devices method
Scan Speed	0,5 mm/sn (when measuring) 1 mm/sn (on the way back)
Measuring Force	4 mN (0,4 gf)
Tip Material	Diamond
Measuring Temperature	20 °C ± 1 °C
Sample Length	0,8 mm
Evaluation Length	4 mm
Tracer End Radius	5 µm
Average surface roughness	$Ra = 1/ln \int_0^{ln} I\, f(x) I \, dx$ (µm)
Ten point height	Rz=(Z1+Z2+Z3+Z4+Z5)-(Z6+Z7+Z8+Z9+Z10)/ 5 (µm)
Maximum roughness	Ry (µm)

2.5. Non-Destructive testing (ultrasonic testing) method

Non-destructive material inspection is the most important part of quality control and is the final integral part of production. Non-destructive testing is the name given to all of the inspection methods in which information about their dynamic and static structures is obtained by inspecting the materials examined without any damage. With the non-destructive testing method, the materials can be detected during manufactur-ing or after a certain period of use, such as cracks caused by corrosion or abrasion, gaps in the internal structure, section reduction, etc. errors are detected. In this study, meas-urements were taken to detect the error of the final materials coming out of the extrusion die made of X38CrMoV5-3 (1.2367) hot work tool steel and Inconel 718 super alloy. The measuring device is SONOWALL 70.

3. Results and Discussion

3.1. Ultrasonic inspection after extrusion

After the mold binding process, the extrusion machine was commissioned and the production of 10X120mm lamella material was realized (Fig 3).

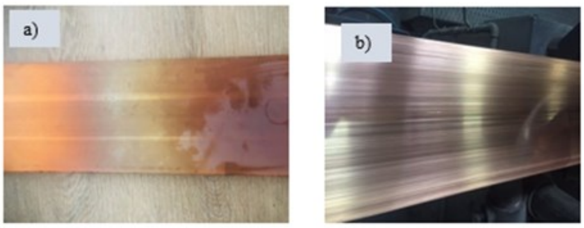

Fig.3. a) X38CrMoV5-3 (1.2367) and b) Inconel 718 extrusion die; visual representation of the final product.

The manufactured products were subjected to ultrasonic inspection test (Fig.4). According to the test result, no defects were found in the interior of the materials coming out of the extru-sion mold made of X38CrMoV5-3 (1.2367) hot work tool steel and Inconel 718 super alloy.

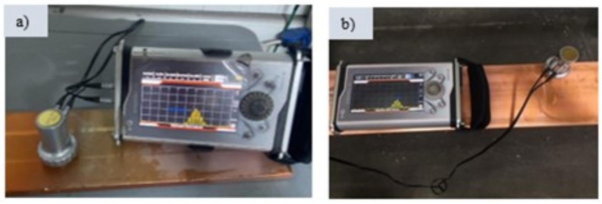

Fig.4. a) X38CrMoV5-3 (1.2367) and b) Inconel 718 extrusion die; Ultrasonic Inspection Test visual display of final products.

3.2. Mechanical properties

Table 3 below shows the mechanical properties of X38CrMoV5-3 (1.2367) hot work tool steel and Inconel 718 superalloy.

Tab.3. Mechanical properties of X38CrMoV5-3 (1.2367) hot work tool steel and Inconel 718 superalloy.

Materials	Inconel 718 Super Alloy (Malz. No: 2.4668)	Hot Work Tool Steel X38CrMoV5-3 (Materal No 1.2367)
Yield strength (MPa)	1170	850
Tensile strength(MPa)	1375	980
Intrinsic impact toughness (J) (+20 ºC)	23	100
Hardness(HB) (+20 ºC)	390 HB	229 HB
%Elongation (20 ºC)	13	16
Coefficient of Thermal Expansion (1/C)	13.0	13.1
Operating Temperature Range (ºC)	-423 and +760	+20 and +500
Density (g/cm^3)	8,19	7,85

When we examine Table 3, when the tensile test results are examined; While the yield strength of the Hot Work Tool Steel X38CrMoV5-3 alloy was 580 MPa, the maximum tensile strength was 980 MPa, the % elongation value was 16% and the yield/tensile strength ratio was 0.86. Looking at the tensile test results of Inconel 718 super alloy for the other alter-native extrusion die; The yield strength was 1170 MPa, the maximum tensile strength was 1375 MPa, while the % elongation value was 13% and the yield/tensile strength ratio was 0.85. Yield and maximum tensile strength values of Inconel 718 Super Alloy are higher than those of Hot Work Tool Steel X38CrMoV5-3. The reason why the % elongation value of the Hot Work Tool Steel X38CrMoEV5-3 alloy is low; phases, grain structure, high hardness values and residual stresses that occur due to rapid heating and cooling during the process prevent deformation during the tensile test [27].

The hardness values of the produced extruded die X38CrMoV5-3 (1.2367) hot work tool steel and Inconel 718 superalloys were determined using a Brinell hardness device. The test involved applying a load of 187.5 N with a ball of 2.5 mm diameter. Samples with a thickness of 10 mm were prepared for the measurements. Hardness tests were applied to each prepared sample five times and the average Brinell hardness values were calculated by measuring the trace diameters. When we examine the hardness values given in Table 3, Inconel 718 Super Alloy was determined as 390 HB, while X38CrMoV5-3 (1.2367) hot work tool steel was determined as 229 HB. Impact toughness values were also measured higher than that of the full course X38CrMoV5-3 (1.2367) hot work tool steel. This relationship between the impact test and hardness test results is an expected result. Because the factors that increase the hardness value in the material decrease the fracture toughness [28,29].

3.3. Surface roughness measurement

Surface roughness measurement was made in terms of the quality of the final materials coming out of the extrusion die made of X38CrMoV5-3 (1.2367) hot work tool steel and in-conel 718 super alloy (Fig 5).

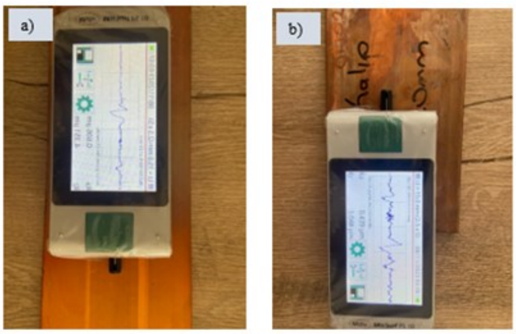

Fig.5. a) X38CrMoV5-3 (1.2367) and b) Inconel 718 extrusion die; display of surface roughness measurement of final products.

As seen in Fig 5, the surface roughness (Ra) value of the product coming out of the X38CrMoV5-3 (1.2367) extrusion die was measured as 0.606 µm. From the Inconel 718 extru-sion die; The surface roughness measurement result (Ra) of the final products was determined as 0.439 µm. Looking at these results, an improvement was observed in the surface roughness of the final products coming out of the Inconel 718 extrusion die.

3.4. Conductivity measurement

Although the conductivity values of the final materials coming out of the extrusion die made of X38CrMoV5-3 (1.2367) hot work tool steel and Inconel 718 super alloy are the same material, there are differences (Fig 6).

Fig.6. a) X38CrMoV5-3 (1.2367) and b) Inconel 718 extrusion die; display of conductivity measurements of final products.

4. Conclusion

The results of this study are summarized below;

• The chemical composition distributions give us the values in the literature and Inconel 718 alloy, with its increasing content and distribution, has highlighted that it is an alternative material for producing extrusion molds that are resistant to thermal fatigue, abrasion and mechanical stresses in longer time in high temperature applications.

• In the ultrasonic inspection test of the manufactured products, no defects were found in the final products coming out of both extrusion molds.

• Yield and maximum tensile strength values of Inconel 718 Super Alloy were higher than Hot Work Tool Steel X38CrMoV5-3 values and the % elongation value was lower.

• As a result of its hardness values, Inconel 718 Super Alloy has a higher value than X38CrMoV5-3 (1.2367) hot work tool steel, while its impact toughness is lower.

• Surface roughness (Ra) measurement results showed improvement in the final product coming out of the extrusion mold made of Inconel 718 super alloy.

• Although the conductivity values of the final materials coming out of the extrusion die made of X38CrMoV5-3 (1.2367) hot work tool steel and Inconel 718 super alloy are the same material, there are differences. Inconel 718 super alloy has a higher conductivity value.

Thanks to these successful process steps, 12 tons of material was produced with 1.2367 (hot tool work steel) quality mold, while the amount of material produced with Inconel-718 quality mold was 40 tons and exhibited the local characteristics expected from it. For this reason, this study has the potential to be an important reference for academic and industrial applications.

Acknowledgments
We would like to express our gratitude to Gemciler Güven Metal San. ve Tic. A.Ş., who has provided the opportunity for the realization of this research study and has made a significant contribution to the success of our work as the financial supporter of the study.

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