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Analysis of The Mechanical Properties of Inconel 718

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Abstract – Super alloys appear as indispensable materials in areas where engineering alloys are used today. What makes these alloys indispensable is that other engineering alloys cannot show the desired mechanical properties under the desired temperature conditions. Especially nickel-based super alloys have become indispensable materials for the aviation industry. While most of the engineering alloys exhibit poor resistance and poor creep behavior at high temperatures, nickel-based super alloys show good strength and good creep behavior even at high temperatures (up to about 650 °C). One of the biggest reasons for the production of the turbine blades in the front of the aircraft engines from nickel-based super alloys is good resistance even in variable temperature conditions (air temperature is around -50 °C when the aircraft is 11 km above the ground and 25 °C at sea level), toughness and good creep properties. While the Inconel 718 alloy gives these strength properties, precipitation hardening mechanism is utilized. This study was made to show how Inconel 718 exhibits mechanical behavior under desired temperature conditions, and to indicate which mechanisms it utilizes while exhibiting these properties, turbine blade design was made in student version of SIEMENS SOLID EDGE. In addition, this design has been analyzed in the ANSYS student version.

Keywords – Super Alloy, Inconel 718, Ansys, Stress Analysis, Design

I. INTRODUCTION

Super alloys are demanded materials in demanding applications as they maintain their strength even when exposed to temperatures above 650 °C for a long time, requiring high performance at high temperatures. These materials developed for high temperature applications have good corrosion and oxidation resistance at high temperatures, superior friction and tensile strength [1, 2].

Heat resistant super alloys with high melting point can be classified in three basic ways: nickel, iron-nickel and cobalt based alloys [3]. Nickel-based super alloys make up 50% of high-tech aircraft engines. Due to their long-term resistance especially at temperatures above 700 °C; They are used in aircraft engines, industrial gas turbines, spacecraft, rocket engines, nuclear reactors, submarines, steam power plants, petrochemical equipment and other high temperature applications [4]. Molybdenum, tungsten, niobium, aluminum, titanium etc. Alloys containing the elements and significantly increasing the resistance of nickel-based alloys have been developed. Inconel 718 is the most important and widely used nickel-based superalloy [5].

Inconel 718 has a wide range of use in the production of turbine engine parts, it has excellent high temperature mechanical properties, as well as good corrosion resistance and ductility [6,7]. Inconel 718 used in both cast and forged forms; It is an indispensable superalloy for the aircraft / space, nuclear and petrochemical industries. Inconel 718 is an alloy whose strength is increased by precipitation hardening mechanism by applying heat treatment. Inconel 718's high temperature strength is included in the class of difficult to machine alloys due to increased cutting forces due to hardening during processing and increased tool temperature due to low thermal conductivity. The low machinability of aircraft engine alloys is due to their own characteristics [5].

Super alloys constitute an important material group with many superior properties. They are used in the manufacture of some parts of jet turbines, most of which are resistant to high temperatures and excessive oxidation at these temperatures. Maintaining mechanical integrity under these conditions (high temperature and oxidation) is a critical issue; Since centrifugal forces are very effective especially in rotating heavy parts, it is very important to use materials with low density. These alloys are divided into three groups as iron-nickel based, nickel based and cobalt based depending on the base metal they contain. Other alloying elements used in these alloys; Refractory metals such as Nb, Mo, W and Ta. In addition to their use in turbines, these alloys are also used in some nuclear reactor parts and some equipment in petrochemical refineries [8].

Superalloys are alloys that contain trace amounts of W, Mo, Ta, Nb, Ti and Al with group VIIIB elements and generally various combinations of Fe, Ni, Co and Cr, developed for use at temperatures above ~ 540 °C [5].

The versatility of super alloys is due to their combination of high strength at high temperature with low temperature ductility and excellent surface stability. Compared to other applications developed for high temperature applications, they are alloys used in applications where more severe mechanical stresses and high surface stability are required [3, 9].

The term super alloy was first used in II. It was used to describe a group of alloys developed for use in turbochargers and aircraft turbine engines requiring high performance at high temperatures shortly after World War II. Examination of the performance of super alloys aimed at increasing fuel efficiency and reducing emissions in modern turbine systems reveals the superiority of these alloys for high temperature applications [10, 11]. The hardness of super alloys can be increased after cold deformation, but this hardness may not be able to withstand high temperatures. Superalloys have high strength not only due to the nature and chemistry of the austenitic face-centered cubic matrix, but also by the effect of precipitating hardening phases [2,3]. Super alloys are classified as nickel, iron-nickel and cobalt based. Iron-nickel based super alloys have lower strength than nickel based alloys. Due to their high melting temperatures, nickel and cobalt based super alloys show higher strength compared to iron-nickel based alloys at high temperatures. For this reason, nickel and cobalt-based alloys are preferred for long-lasting applications and also for high mechanical stresses. Iron-nickel-based superalloys are used more than cobalt or nickel-based superalloys because of their low cost at lower temperatures and depending on the type of strength required [5].

The Inconel 718 was developed by International Nickel Corporation in the 1950s, although it was developed long ago, it has wide range of uses today, especially for many materials operating in high temperature environments such as aircraft / industrial gas turbine engine parts. Thermal fatigue strength, oxidation resistance, corrosion resistance, easy malleability and weldability are important features of Inconel 718 [13].

Inconel 718 belongs to the group of nickel-based super alloys containing 18-19% iron and is hardened thanks to the coherent HMT γ '' (Ni3Nb) phase. The iron content acts as a catalyst for the metastable γ 'formation. It contains low amounts of aluminum and titanium, providing 3-5% by weight of Nb and γ '(Ni3Al, Ti) phase formation. Inconel 718 alloy has an orthorhombic crystalline stable delta (δ) phase with a chemical composition of Ni3Nb. Since appropriate heat treatment methods are important for this alloy, the heat treatment conditions required for the realization of the desired phase transformation can be determined by examining the temperature-time-transformation (TTT) diagram [12]. Although the Inconel 718 is matrix consists of NbC, γ ', γ' 'and δ phases, the alloy hardening effect of the γ' 'phase is quite high. Although it does not have a major role as' ', the γ' phase also affects the hardness, but the phase formed in the structure has negative effects on the mechanical properties [14]. γ "" Due to the precipitation phase instability, the maximum use temperature of Inconel 718 is ~ 650 °C. Inconel 718 is one of the super alloys with the highest strength and the widest usage area, but it loses its strength rapidly in the temperature range of 650 ºC – 815 ºC. This loss in the high temperature resistance of Inconel 718 is related to the matrix / precipitate high lattice mismatch formed by the γ '' phase deposited in the austenitic matrix. Figure 3.1 shows the mechanical properties change of Inconel

718 alloy at room temperature and 650 °C. When its physical properties are examined, it is seen that it has a density of 8.19 g / cm3 and a melting temperature of 1260 °C-1336 °C. The % elongation value at 650 °C does not differ from the value at room temperature [5].

Inconel 718 has the characteristic of being machinable at values below stainless steels as in other nickel based super alloys. Nevertheless, due to parameters such as the appropriate cutting edge material, machining method, cutting speed and depth of cut, it can be processed in solid solution or aged condition. While the solid solution alloy provides easier machinability and longer insert life during machining, the aged alloy supports more chip formation and a better surface quality is obtained at the end of machining [5].

Factors that make Inconel 718 harder to process are its high strength and deformation hardening (hardening) during processing. The presence of abrasive hard carbides in the microstructure causes insert wear, which increases machining costs during machining [15, 16].

The mechanical properties such as sufficient strength, good ductility, high temperature creep resistance, which make the Inconel 718 alloy special, are provided by controlling the particle size and amount of the γ ', γ' 'and δ phases. The use of the Inconel 718 as a medium temperature turbine disc is common in aircraft gas turbine engines. At the same time, it is among the world's leading forged super alloys among other alloys since the 1970s [5].

Its excellent mechanical properties, especially up to 650 °C, made Inconel 718 the material used in world-class turbine discs. Obtaining homogeneous and desired ductility, satisfactory fatigue resistance and sufficient creep resistance for the highest application temperature made Inconel 718 the preferred material for turbine discs. Inconel 718 has excellent corrosion and oxidation resistance as well as good formability, excellent strength, ductility and toughness between -217 °C and 705 °C [5].

Good seawater corrosion resistance has made this alloy usable in marine applications. Inconel 718 used in both cast and forged forms; It is an indispensable material for the aircraft / space, nuclear and petrochemical industry. In aircraft applications; It is used in aircraft engine parts such as compressors, turbine disks, turbine blades, bolts, cryogenic tanks (used at temperatures of -162 °C), and power supply batteries of satellites [16].

II. MATERIALS AND METHOD

In this study, an aircraft engine was drawn using the Siemens Solid Edge drawing program and comparing the strength of structural steel with Inconel 718 using Ansys Workbench 2020 R2 program.

First we need to make a design. For this, we take the turbine blades section of the aircraft engine designed using the student version of the SIEMENS SOLID EDGE Program and introduce it to our project. 3D part drawn in SIEMENS SOLID EDGE Program is given in Fig. 1. Then we open the ANSYS Workbench 2020 R2 program to analyze the piece we have drawn. After opening the program, the ANSYS interface welcomes us.

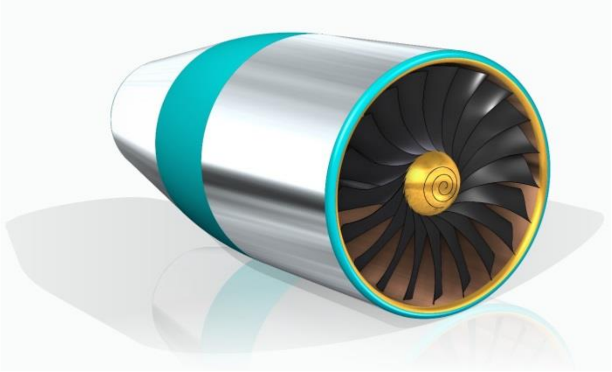

Fig. 1 3D Part Drawn in SIEMENS SOLID EDGE Program

Here, by double-clicking on the Static Structural section, we open our project (Fig. 2). Then, we double click on Engineering Data to assign materials (Fig. 3).

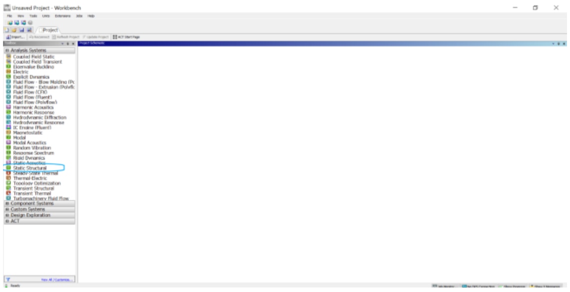

Fig. 2 Static Structural Section

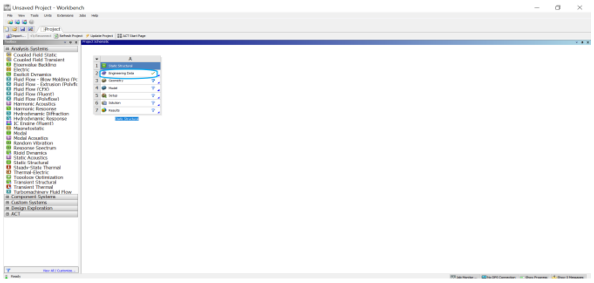

Fig. 3 Engineering Data Section

Then, we click once on Engineering Sources section from above (Fig. 4). There are almost all material types in the ANSYS library here, but if we cannot find the material we want, we can assign a material by clicking the add a new material section.

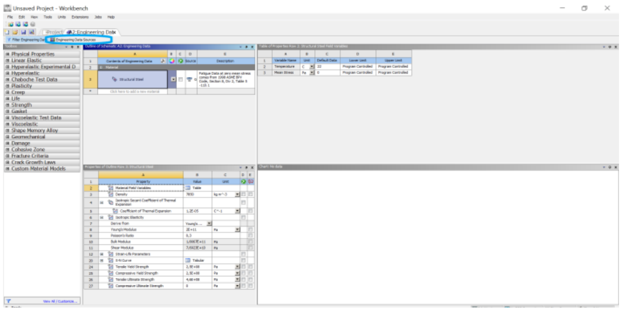

Fig. 4 Engineering Data Sources Section

After assigning the material, we should introduce our row geometry to our project. We can find our geometry from the import geometry section (Fig. 5).

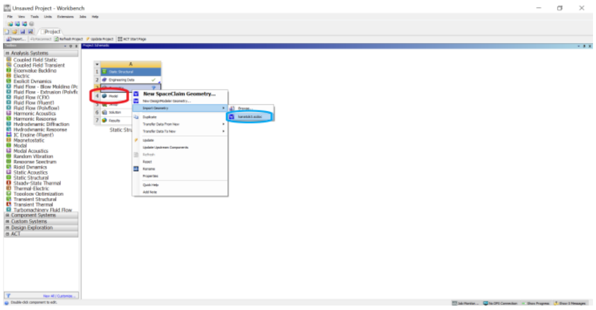

Fig. 5 Import Geometry Section

Then double-click the Model part to open the Mechanical mode, in this mode we set the parameters required for analysis. First, we have to mesh our geometry. This process is essential and important for strength calculations. The equations working behind the program progress by solving these finite elements. Here, we have done the process of separating the part into geometric parts as much as possible in the smallest size and with the mesh process. We do the mesh operation by clicking the Generate Mesh button (Fig. 6).

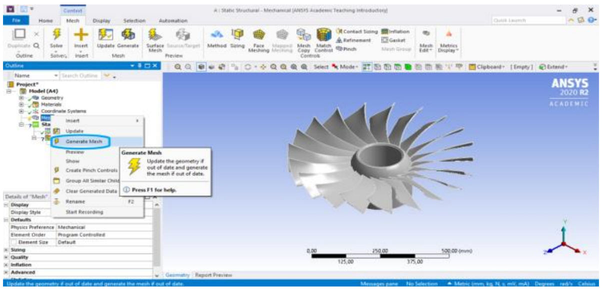

Fig. 6 Mesh Process

After the process, we cut the piece into small pieces with a known geometry (Fig. 7).

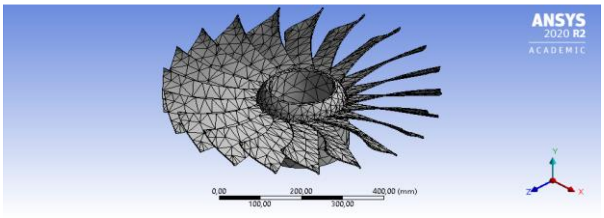

Fig. 7 Mesh View of the Part

Then we define the temperature of the part, from where the part will be fixed and load the force respectively (Fig. 8).

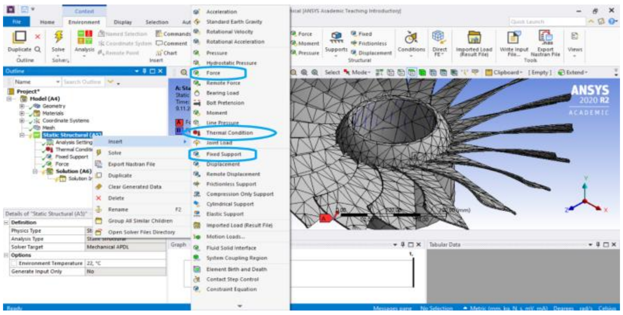

Fig. 8 Loads made to the part with the Insert Part

Finally, we tell the program what solutions we want in the solution of the part. Here, we will interpret the part according to the Von-Mises damage theory (Fig. 9).

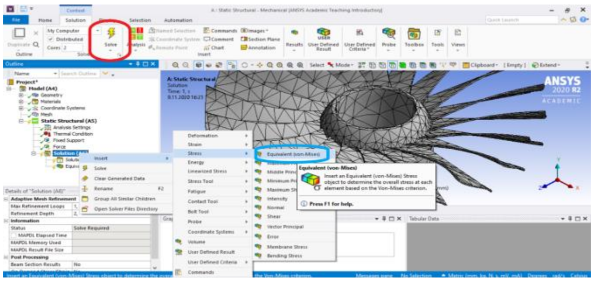

Fig. 9 Interpreting the Part According to the Von-Mises Damage Theory

Finally, the Solve button is clicked and the results are displayed. The next step will be to examine the results.

III. RESULTS AND DISCUSSION

Inconel 718 is a material with high creep behavior at high temperatures as it is known under hot conditions. Therefore, structural steel and our Inconel 718 material were analyzed with 100 Newton at 22 °C, 300 °C and 600 °C. Let's evaluate the results of these analyzes. First, let's interpret the results at 22 °C. Structural Steel and Inconel 718 results are given in Fig. 10 and Fig. 11, respectively.

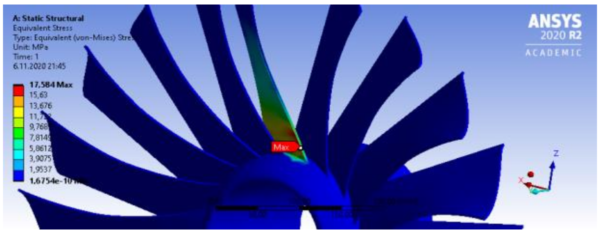

Fig. 10 Results of Structural Steel at 22 °C According to Von-Mises Damage Theory

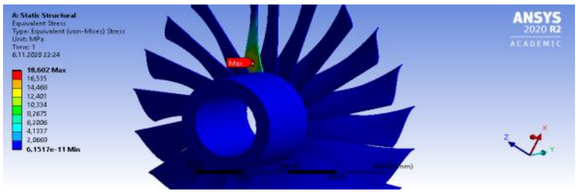

Fig. 11 Results of Inconel 718 at 22 °C According to Von-Mises Damage Theory

Looking at the results, structural steel shows a better strength at room temperature. While the maximum tensile value seen in structural steel is 17.584 MPa, the maximum tensile value seen in Inconel 718 is 18.602 MPa.

Analysis results of structural steel and Inconel 718 at 300 °C are given in Fig. 12 and Fig. 13, respectively.

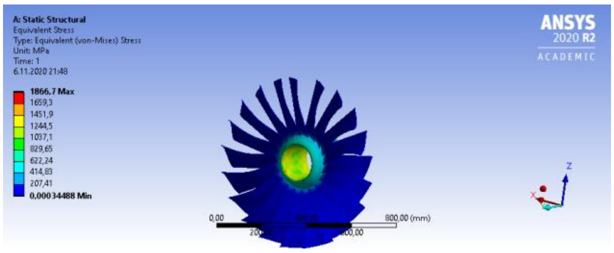

Fig. 12 Results of Structural Steel at 300 °C According to Von-Mises Damage Theory

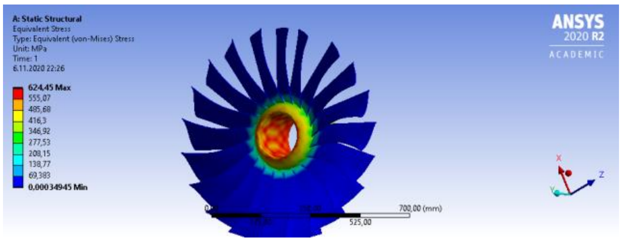

Fig. 13 Results of Inconel 718 according to Von-Mises Damage Theory at 300 °C

When the results are evaluated, the strength of Inconel 718 has started to show itself with the increase in temperature. While the maximum stress of the structural steel is around 1866 MPa, the maximum stress of Inconel 718 is around 624 MPa. As we can understand from here, creep behavior started to show itself at high temperatures. Creep can also be defined as the behavior of the material against deformation under constant stress at high temperatures. Thanks to the sediments, slipping at the grain boundaries is prevented and the shape of the part under force is prevented.

Stress value of structural steel according to Von-Mises damage theory at 600 °C is given in Fig. 14, and damage analysis of Inconel 718 material according to Von-Mises theory is given in Fig. 15.

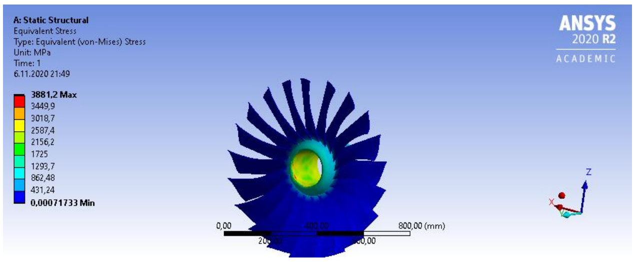

Fig. 14 Results of Structural Steel According to Von-Mises Damage Theory at 600 °C

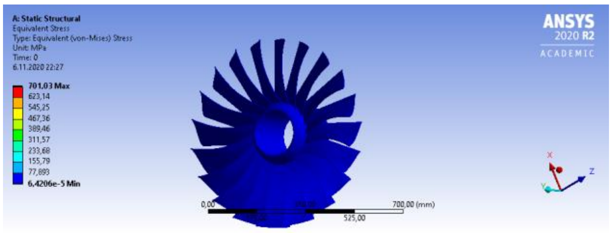

Fig. 15 Results of Inconel 718 according to Von-Mises Damage Theory at 600 °C

When the results are examined, the strength and risk of damage of Inconel 718 Superalloy is higher than structural steel, as expected at high temperatures according to the damage theory. While the maximum stress of the structural steel is around 3881.2 MPa, the maximum stress of Inconel 718 is around 701.03 MPa.

IV. CONCLUSION

When the results are examined, it is seen that the strength of Inconel 718 superalloy at high temperatures is clearly higher than structural steel, as expected when the materials are tested at 22 ^{o}C, 300 ^{o}C and 600 ^{o}C, respectively. The mechanism that provides this is the mechanism that occurs in the form of grain boundary shift at high temperatures, which we know as creep behavior. When it is examined the maximum values seen in materials under a constant force at about 600 ^{o}C, it is seen that the maximum stress of the structural steel is around 1866 MPa, while the maximum stress of Inconel 718 is around 624 MPa. As it can be understood from here, creep behavior started to show itself at high temperatures. Creep can also be defined as the deformation behavior of the material under constant stress at high temperatures. Thanks to the sediments, slipping at the grain boundaries is prevented and the shape change of the part under constant stresses is prevented. Since these precipitates will begin to dissolve at about 600 ^{o}C, Inconel has limited the use temperature of our alloy to 600 ^{o}C, but this temperature is a relatively high temperature compared to conventional engineering alloys. Therefore, super alloys will continue to appear as indispensable materials in applications where high temperatures are required.

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