A NEW SUPERALLOY: ALLVAC 718 PLUS

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Abstract- Along with technological improvements, the breakthroughs in the civilian and military aviation industry enhance the use of products that can function on more crucial conditions. Material properties, one of the most important factors in mechanical design, are an important field that has emerged in recent years. In this study, ALLVAC 718 Plus, which is a newly developed superalloy, has been discussed. In addition, metallurgical and mechanical properties of ALLVAC 718 Plus superalloy are reviewed in accordance with early studies. A new machining method namely, Ultrasonic Assisted Machining (UAM) is proposed for this new superalloy.

Keywords- ALLVAC718 Plus, Superalloy, Mechanical Properties.

I. INTRODUCTION

ALLVAC 718 Plus has been introduced to the market by ATI ALLVAC PROPERTIES. This newly developed nickel-based material offers high temperature resistance and workability together [1,2]. ALLVAC 718 Plus is expected to have widespread use in industries such as aerospace, transportation, petrochemicals as it can be used at temperatures above 650°C. Inconel 718 is a nickel-based superalloy, which is used in high temperatures in these industries. Strengthening of Inconel is achieved by precipitation hardening of the niobium element. Since the hardening phase γ" is not fully stable, it is difficult to use this alloy above 650°C. Another alloy that can be used above 650°C temperature is Waspalloy. The strengthening phase of Waspalloy, γ' is stable at high temperatures however, poor machinability causes high cost for Waspalloy in manufacturing. At this point, ALLVAC 718 Plus emerges as a material that meets the needs[3].

Table 1: Chemical Composition of Inconel 718 and ALLVAC 718 Plus [6]

<table>
<thead>
<tr>
<th></th>
<th>Cr</th>
<th>Co</th>
<th>Mo</th>
<th>W</th>
<th>Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>718</td>
<td>19</td>
<td>---</td>
<td>3</td>
<td>---</td>
<td>5.15</td>
</tr>
<tr>
<td>718 Plus</td>
<td>18</td>
<td>9.1</td>
<td>2.7</td>
<td>1.0</td>
<td>5.4</td>
</tr>
<tr>
<td>Al Ti Fe C P</td>
<td>0.6</td>
<td>0.9</td>
<td>18.5</td>
<td>0.04</td>
<td>0.007</td>
</tr>
<tr>
<td>718 Plus</td>
<td>1.45</td>
<td>0.75</td>
<td>9.5</td>
<td>0.02</td>
<td>0.006</td>
</tr>
</tbody>
</table>

ALLVAC 718 Plus is derived from alloy 718. Compared to Inconel 718, the Al+Ti content and the Al/Ti ratio are high. In addition, Fe content is reduced while W and Co elements are included in the chemical composition. With these modifications, the temperature resistance of Inconel 718 up to 650°C is increased by 55°C in the ALLVAC 718 Plus [4,5].

Table 2: Properties of ALLVAC 718 Plus [7]

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>8.25 g/cc</td>
</tr>
<tr>
<td>Hardness, Rockwell C (heat treated)</td>
<td>25 - 35</td>
</tr>
<tr>
<td>Hardness, Rockwell C (fully aged)</td>
<td>42 - 48</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>1480 MPa</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>1170 MPa</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>25%</td>
</tr>
<tr>
<td>Thermal Expansion Coefficient</td>
<td>12.3 µm/m°C</td>
</tr>
<tr>
<td>Heat Capacity (at 260°C)</td>
<td>0.520 J/g°C</td>
</tr>
<tr>
<td>Thermal Conductivity (at 260°C)</td>
<td>13.7 W/m-K</td>
</tr>
<tr>
<td>Melting Point</td>
<td>1260 - 1343 °C</td>
</tr>
<tr>
<td>Solvus</td>
<td>1260 °C</td>
</tr>
<tr>
<td>Liquidus</td>
<td>1343 °C</td>
</tr>
</tbody>
</table>

II. MICROSTRUCTURE AND HEAT TREATMENT OF ALLVAC 718 PLUS

Microstructure of hot forged ALLVAC 718 Plus consists of FCC austenitic matrix while having a grain size of about 50 µm. As shown in Figure 1, there are MC type carbides in the microstructure and these carbides are Nb-rich containing Ti and C [4].

In the initial development of ALLVAC 718 Plus, Inconel 718 alloy was heated to 954°C and followed an aging process at 718°C and rested at 621°C. Later, it has been understood that higher aging temperatures...
are required for optimum properties. Accordingly, the proposed heat treatment is given below.

- Solution heat treatment at 954°C - 982°C for 1 h
- Fast cooling (air or faster) to room temperature
- Aging at 788°C for 2 - 8 h
- Furnace cooling with 38°C/h
- Resting for 8 h at 704°C
- Cooling to room temperature in the air

Optimum mechanical properties for 718 Plus are obtained by the rod-shaped δ phase at grain boundaries as seen in Figure 2a. When using extremely high forging temperatures, δ phase is either not formed in the microstructure or exists in very small quantities. This leads to an increase in fracture cracks. No crack breakage is observed as δ phase appears at the dissolution temperature at 954°C. However, as shown in Figure 2b, δ phase is formed excessively at the grain boundaries in case of extremely long heating and therefore, tensile strength of the material is reduced. This is the basic mechanism, although there is not sufficient work done in this regard [5].

**Fig.2.** (a) Optimal quantity and (b) excessive quantity of δ phase at grain boundaries [5]

### III. MECHANICAL PROPERTIES

The mechanical properties of ALLVAC 718 Plus have been characterized by many mechanical tests reported by manufacturers and researchers. The yield strength and elongation of ALLVAC 718 Plus at different temperatures are shown in Figure 3 with Inconel 718 and Waspalloy. According to the graph, the yield strength of Inconel 718 is higher than ALLVAC 718 Plus up to 650°C. However, the advantage of ALLVAC 718 Plus over the temperature of 650°C is obvious. Furthermore, the ductility of all three alloys seem to be high with an elongation rate of approximately 20% at all temperatures [5].

**Fig.3.** Mechanical properties of ALLVAC 718 Plus with various alloys [5]

Regarding to creep strength, ALLVAC 718 Plus, Inconel 718 and Waspalloy were tested at 704°C by applying 483 MPa stress to round bar samples with diameter of 150-200 mm. ALLVAC 718 Plus withstands the loading for approximately 380 h. However, Inconel 718 and Waspalloy fail after 120 h and 180 h, respectively. It is obvious that ALLVAC 718 Plus is resistant against creep for longer than other superalloys. ALLVAC 718 Plus alloy exhibits a hardness between 25-35 HRC after solution heat treatment, whereas 42-48 HRC after full aging treatment. Figure 4 shows the hardness characteristics of ALLVAC 718 Plus, Inconel 718 and Waspalloy according to aging at 704°C [1]. In another investigation, fatigue properties of ALLVAC 718 Plus were studied. For this reason, the samples were loaded at 650°C for 3 s cycles. The results were compared with different superalloys and it was stated that ALLVAC 718 Plus has a slightly better fatigue characteristic compared to Inconel 718. However, Waspalloy exhibits the superior fatigue resistance among the samples. Based on the scanning electron microscope (SEM) investigations, ALLVAC 718 Plus shows transgranular crack propagation at room temperature while at 650°C, crack path is both transgranular and intergranular [5].

**Fig.4.** Hardness of ALLVAC 718 Plus with various alloys [5]

### IV. MACHINABILITY PROPERTIES

ALLVAC 718 Plus alloy has positive properties in terms of machinability whether it is in the form of solution heat treated or aged. Investigations into ALLVAC 718 Plus exhibit that the machinability properties of this new alloy is the same as the 718 alloy [1]. Based on this statement, new machining operations can be adapted for ALLVAC 718 Plus. Therefore, this novel alloy can be extended in the engineering applications especially under high temperature conditions. Ultrasonic assisted machining (UAM) is an attractive method for the machining operations of refractory materials such as superalloys. The method is based on intermittent cutting of the material to reduce cutting forces and heat generation in the cutting zone as
shown in Figure 5. The intermittent cutting is enabled through an excitation on the cutting tool that is generated with an ultrasonic generator. The operation uses 20 kHz frequency and amplitude between 10-20 µm to obtain the advantages such as improved tool life and reduced surface roughness [9,10].

![Image](image_url)

**Fig.5. UAM operation [11]**

Early studies [12,13] observed beneficial outputs applying UAM operation for Inconel 718. For example, residual plastic strain after this operation reduces in comparison with conventional cutting method. This finding is very significant considering the service life of the material in particular, for the components in aerospace applications. Besides, the heat generation in the cutting zone lowers the UAM operations and therefore detrimental effects of cutting temperature on the material are reduced while increasing tool life.

It is also suggested that hardness of the machined surface remains closer to that of the untreated material while conventional cutting method drastically increases the hardness and disrupts the surface characteristics of the material. As a result, UAM operation seems to be convenient for ALLVAC 718 Plus since the machinability properties of this alloy is quite similar with Inconel 718.

**V. WELDABILITY PROPERTIES**

In literature, there are not many studies for the weldability of ALLVAC 718 Plus alloy. Nevertheless, the investigations indicate that weldability properties of ALLVAC 718 Plus are favorable. In comparison to Waspalloy, the weldability of ALLVAC 718 Plus is close to 718 alloy. Figure 6 shows the weldability characteristics of alloys due to the influence of alloying chemistry on the formation of post-weld heat treatment cracks. According to the graph, ALLVAC 718 Plus is located in easily weldable region [1,14]. ALLVAC 718 Plus is a proper material for gas-protected arc welding, plasma arc welding, electron beam welding (EBW) and resistance welding methods. Aged alloy can be welded repeatedly without cracking problem [1].

**VI. FORGEABILITY PROPERTIES**

ALLVAC 718 Plus exhibits good hot forming characteristics. Temperatures up to 1121°C can be used in the first stages of the forging process. The final stages of the forging start between 982°C-1038°C depending on the part geometry. At the end of the forging process, temperature is reduced by approximately 25% and the process is completed at a lower temperature between 899°C-982°C. By this means, a small amount of δ phase is formed at grain boundaries [1].

**CONCLUSIONS**

ALLVAC 718 Plus is expected to be used in aerospace industry due to high temperature resistance, convenient machinability and appropriate raw material cost. High pressure turbine discs and high pressure compressor discs are possible application areas for this alloy. This superalloy gives the researcher a sense of similarity to Inconel 718 in terms of metallurgical properties. However, in order to understand the potential of this alloy, more studies need to be done. In virtue of its thermal stability, ALLVAC 718 Plus can withstand up to 55°C hotter conditions than 718 alloy. At 704°C, it has higher creep and tensile strength than Waspalloy. ALLVAC 718 Plus is also offers a reasonable cost compared to the other superalloys. Having these properties, ALLVAC 718 Plus can be considered as a superior material because of the shortcomings of Inconel 718 and Waspalloy.

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