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54 **Weldable cast nickel base superalloy.**

57 The weldability of Inconel 718 material is enhanced by careful control of silicon, columbium and carbon levels. Minimization of the sulfur, phosphorous and boron levels is also a part of the invention it serves to further minimize the microcracking in the heat affected zone which would otherwise be observed.

**FIG. 1**



**1000X**

## Description

## Weldable Cast Nickel Base Superalloy

This invention relates to compositional modifications of, a nickel base superalloy, Inconel<sup>®</sup>718 (a product of the International Nickel Co., Inc.) to render it consistently weldable.

Inconel 718 is a nickel base superalloy developed in the 1960s which has particular application in gas turbine engines. The nominal content of the required elements is 5.12% niobium plus tantalum, 19% chromium, 52.5% nickel, 3.05% molybdenum, 0.9% titanium, 0.6% aluminum, balance iron. Additionally, limits are placed on certain impurity elements such as silicon with a maximum of 0.3%, carbon with a maximum of 0.8% sulfur with a maximum of 0.015%, and manganese with a maximum of 0.35%. Inconel 718 is a moderate strength material particularly useful in the temperature range of about 538° C-816° C (1000 - 1500° F) and is apparently the subject of U.S. Patent No. 3 046 108.

In the past the alloy has been used in wrought form in which case it can be bent or otherwise formed into useful shapes, and in cast form in which case the geometry of the shape is essentially established by the casting process. Intricate shapes and close tolerance dimensions in both wrought and cast forms can also be achieved through machining.

Modern gas turbine engines contain parts of substantially increased complexity compared to those of past generation engines. In addition, there is a great impetus to reduce the weight of engines so that whereas in past engines excessive material in castings was tolerated, in present engines there is a desire to remove all excess material. Concurrently there have been advances in the casting art so that parts of increased complexity can now be cast in almost final or net shape requiring minimum finish machining. At the same time there has also been an increase in both use temperature and applied stresses so that there has been a driving force to go to stronger materials.

All of these factors drive the gas turbine engine designer to seek to use complex cast parts of compositions such as Inconel 718. The major problem in making such complex parts is that Inconel 718 is somewhat prone to defect formation (including inclusions, shrinkage and cracks) during casting so that the casting of Inconel 718 to date has provided a relatively low yield of complex flaw-free parts. Accordingly, the practical application of complex cast parts of Inconel 718 is dependent upon the ability to weld repair castings which exhibit minor cracks and similar defects in noncritical areas. It would also be useful to have the capability to repair minor machining flaws. The Inconel 718 composition however desirable in other respects has historically suffered from a lack of consistent weldability.

The cracking encountered in welding Inconel 718 has been analyzed and it was observed that the cracking, more properly described as microcracking, occurs in grain boundaries in the heat affected zone. The heat affected zone is that zone immediately adjacent the weld zone which has not itself melted during welding.

Manual GTA (gas-tungsten-arc) welding has been used to evaluate the invention but it is believed microcracking associated with other types of welding will also be reduced. Material in the heat affected zone is heated to high temperatures during welding. Microcracking appears to occur as the result of localized melting of grain boundaries in the heat affected zone and separation of the grain boundaries upon cooling as a result of mechanical restraints.

The cracking is associated with the presence of Laves type phases in the heat affected zone grain boundaries which have melted and resolidified and MC carbides in these same boundaries. Grain boundary melting has previously also been associated with high concentrations of melting point depressant impurities such as sulfur boron and phosphorus. Figure 1 is a photomicrograph at a magnification of 1000X showing the appearance of a grain boundary in the heat affected zone (in Inconel 718) which has melted and resolidified after welding. A clear indication of extraneous phases can be seen in the center of the melted boundary, and there is evidence of cracking and/or void formation in the boundary, associated with the extraneous phase. Figure 2 is a 1000X scanning electromicrograph photograph of a crack or a void found at the center of a grain boundary in a heat affected zone, the lumpy or rounded crack surface morphology strongly suggests that the crack surface was formed from molten metal, i. e. the cracking occurred before solidification was complete.

Table I shows the composition of the base alloy material, the composition of the grain boundary away from the weld zone and the composition of the grain boundary near the weld zone where cracking was observed. The reference letters in Table I corresponds to the letters in Fig. 1. The grain boundary near the weld zone also contain the previously referred to Laves phase. From the table it is seen that the composition at the grain boundary near where the weld zone has solidified is substantially increased in silicon (by about 10X) and in niobium (by about 6X) from the base metal composition. Figure 3 shows a S.E.M. photomicrograph in which techniques have been employed to enhance the contrast of MC carbides and it can be seen that there is a pronounced concentration of MC carbides in the heat affected zone grain boundary.

All these factors led to a decision to reduce the overall concentration of the niobium, the silicon and the carbon content. By reducing the niobium content from the standard specification range of 4.75-5.5% total for niobium plus tantalum (where tantalum is commonly occurring impurity in niobium which generally has the same alloying effects as

TABLE I

| Element | (A)<br>Base Metal | (B)<br>Grain Boundary<br>(Wide Zone) | (C)<br>Grain Boundary<br>(Centerline Phase) |    |
|---------|-------------------|--------------------------------------|---------------------------------------------|----|
| Ni      | 51.4              | 51.4                                 | 37.2                                        | 5  |
| Co      | --                | --                                   | 0.3                                         | 10 |
| Cr      | 19.1              | 18.2                                 | 12.4                                        |    |
| Ti      | 1.1               | 1.0                                  | 1.1                                         | 15 |
| Al      | 0.75              | 0.75                                 | 0.3                                         |    |
| Fe      | 19.1              | 18.1                                 | 11.6                                        | 20 |
| Mo      | 3.2               | 2.8                                  | 7.4                                         |    |
| Nb      | 5.3               | 5.3                                  | 29.7                                        | 25 |
| Si      | 0.1               | 0.1                                  | 1.0                                         |    |

niobium ) to 4.75-5.125, limiting the silicon level, which is generally permitted in amounts up to 0.35%, to a maximum of 0.05% and changing the carbon content from the commercial specification of up to 0.1% to from 0.03-0.06%, weld related microcracking can be substantially eliminated. Additionally, the sulfur, zirconium, boron and phosphorus levels are preferably reduced to the lowest values commercially practical. It is theorized that the success in eliminating weld cracking which is observed in the compositions modified according to the present invention may be the result of a two-step sequence of events. First by reducing the boron, sulfur, zirconium and phosphorus (all of which are prone to concentrate at grain boundaries and are melting point depressants) melting of the grain boundaries in the heat affected zone may be substantially reduced. Second, for the reduced amount of grain boundary melting which does occur in the modified composition, the reduction of the niobium and silicon substantially eliminates the formation of the deleterious Laves phase. In addition by limiting the carbon content the amount of the MC carbide phase which forms is also reduced.

The foregoing, and other features and advantages of the present invention, will become more apparent from the following description and accompanying drawings.

Figure 1 is a photomicrograph of a grain boundary in the heat affected zone.

Figure 2 is a S.E.M. photomicrograph showing voids associated with grain boundaries.

Figure 3 is a S.E.M. photomicrograph showing M.C. carbides in grain boundaries.

The best mode for carrying out the invention is first to limit the total content of niobium plus tantalum in the Inconel 718 composition to be between 4.75 and 5.125%, to limit the silicon level to a maximum of 0.05% and to change the carbon range to 0.03-0.06%. Also it is highly preferred to limit the sulfur, zirconium, boron and phosphorus contents to be as low as possible in consistent with commercial practice. The reduction of the sulfur, zirconium, boron and phosphorus is best achieved through the use of good modern practice in conjunction with the use of virgin starting materials, that is to say the use of pure individual starting elements rather than the use of revert or scrap material as starting material.

Table II shows composition and weld test results of ten samples of Inconel 718 material. Seven of the ten samples were special test samples with controlled chemistries (according to the present invention) produced from virgin material, the remaining three samples were commercial engine parts produced in one case from virgin material and in two cases from revert

TABLE II  
CHEMISTRY CORRELATION WITH MICROCRACKING

| Material | Si    | Nb   | C     | <254 $\mu\text{m}$ | Microcrack Population<br>279-762 $\mu\text{m}$ | > 787 $\mu\text{m}$ |
|----------|-------|------|-------|--------------------|------------------------------------------------|---------------------|
| #1 (1)   | 0.08  | 5.1  | 0.048 | 2.0                | 0.0                                            | 0.0                 |
| #2       | 0.06  | 4.9  | 0.051 | 0.0                | 0.0                                            | 0.0                 |
| #3       | 0.008 | 5.2  | 0.062 | 3.5                | 2.5                                            | 1.0                 |
| #4       | 0.015 | 4.7  | 0.046 | 5.0                | .75                                            | 0.0                 |
| #5       | 0.018 | 5.1  | 0.061 | 3.25               | 5.5                                            | 0.25                |
| #6       | 0.037 | 5.0  | 0.048 | 0.0                | 1.5                                            | 0.0                 |
| #7       | 0.040 | 4.9  | 0.058 | 0.0                | .5                                             | 0.0                 |
| #8       | 0.004 | 4.75 | 0.047 | 1.33               | 0.0                                            | 0.0                 |
| #9 (2)   | 0.14  | 4.9  | 0.062 | 18.0               | 13.0                                           | 2.0                 |
| #10 (2)  | 0.15  | 5.1  | 0.050 | 18.0               | 13.0                                           | 1.0                 |

(1) Commercial engine part; virgin material  
(2) Commercial engine part; revert material

or scrap material. The Table generally supports the thesis of the invention, that excessive amounts of silicon, niobium and/or carbon result in increased microcracking. The Table also supports the desirability of using

virgin material inasmuch as the two samples produced in part from revert or scrap material had by far the highest microcracking. Samples number three and five which had niobium level at the high at or above upper end of the invention limit displayed the highest cracking levels of any of the virgin samples tested. Samples three and five also had carbon contents at the high end of those permitted by the invention limits. Accordingly it is believed that this data substantiates the affects of carbon, silicon and niobium and the weldability of alloy Inconel 718 and that by limiting these elements as previously set forth the weldability of Inconel 718 can be substantially enhanced.

Although this invention has been shown and described with respect to detailed embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail thereof may be made without departing from the spirit and scope of the claimed invention.

## Claims

1. Process for improving the weldability of an alloy whose normal composites essentially of:

17-21% Cr

50-55% Ni

2.8-3.0% Mo

0.65 - 1.15% Ti

0.2 - 0.8% Al

4.75-5.5% (Nb + Ta)

up to 0.10% C

up to 0.35% Si,

balance iron along with normally occurring minor impurities, characterized in modifying the alloy composition by

limiting the (Nb + Ta) level to the range of 4.75 - 5.1,

limiting the Si level to 0.05% maximum,

and changing the carbon content requirement to 0.03-0.06%

whereby said modified alloy is rendered substantially weldable and is substantially free from cracks in the heat affected zone after welding.

2. An alloy whose normal composites essentially of:

17-21% Cr

50-55% Ni

2.8-3.0% Mo

0.65-1.15% Ti

0.2-0.8% Al

4.75-5.5% (Nb + Ta)

up to 0.10% C

up to 0.35% Si,

balance iron along with normally occurring minor impurities, characterized by the improvement which comprises modifying the alloy composition by

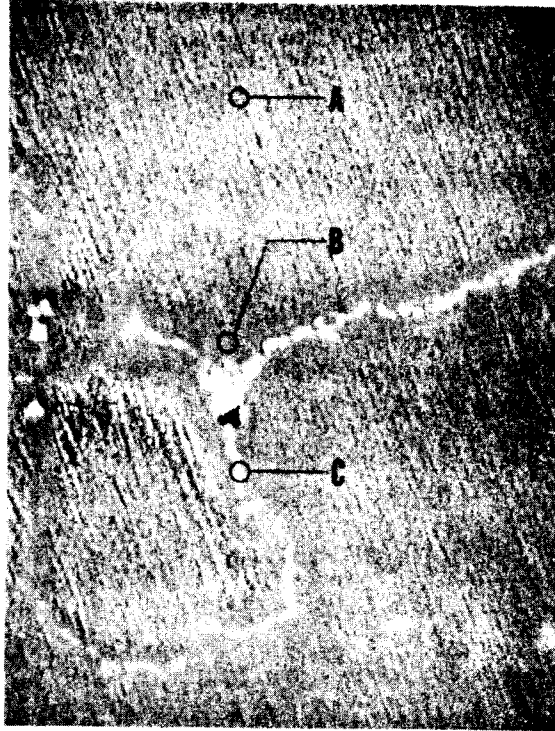
limiting the (Nb + Ta) level to the range of 4.75-5.1,

limiting the Si level to 0.05% maximum,

and changing the carbon content requirement to 0.03-0.06%

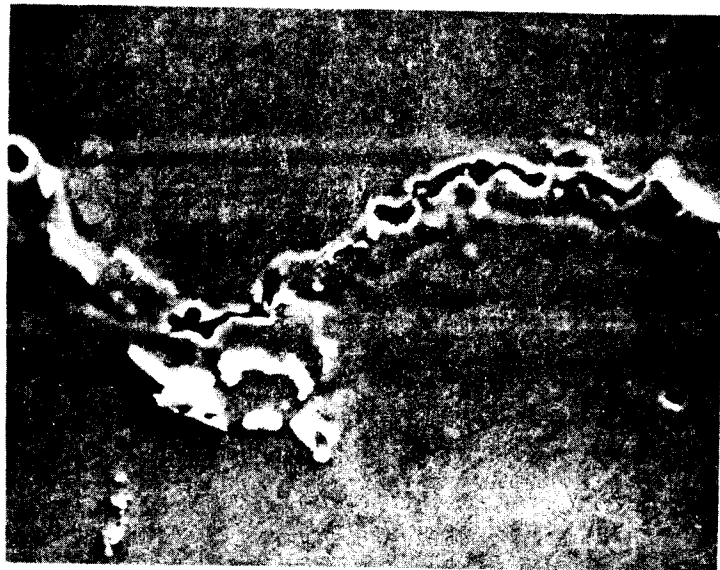
whereby said modified alloy is rendered substantially weldable and is substantially free from cracks in the heat affected zone after welding.

FIG. 1



1000X

FIG. 2



1000X

0225270



1000X

**FIG. 3**