

# Some Problems in Welding Inconel 718

There are problems in welding Inconel 718—obtaining good penetration, micro-fissuring, and developing adequate impact strength and ductility—but these problems can be overcome by adequate control and selection of the proper solution heat treatments.

BY J. GORDINE

## Introduction

Inconel 718 is a nickel-base, precipitation hardenable alloy suitable for service at temperatures from  $-423$  to  $1300$  F. It was originally developed for gas turbine application as an alloy with high strength (up to  $190,000$  psi UTS) and sluggish aging characteristics which afford a high degree of metallurgical stability during fabrication. However, its sea water corrosion properties also make it an attractive material for high strength marine structural applications, and it is in this role that it is being studied by the Canadian navy. Consideration has been given for its use in a hydrofoil ship where it would be used for the leading edges of the foils and possibly for the supercavitating propellers. It was the purpose of this program to evaluate the problems involved in welding the alloy. Three main problem areas were encountered and investigated: (1) poor penetration during welding; (2) microfissuring in the heat affected zone; and (3) poor impact and ductility properties of the weld fusion zone.

## Penetration

In general, Inconel 718 has very good weldability. Welding tests were made using gas metal-arc (GMA) and gas tungsten arc (GTA) processes and satisfactory results were obtained. Welds were also made in the unaged and aged conditions and no major difficulties arose. The one problem always encountered was the difficulty of obtaining good penetration with the root pass. This is encountered in most nickel-base alloys and is due to the poor fluidity of the molten metal. It was therefore decided to study this aspect more closely and to try to obtain quantitative data upon how the penetration is affected by various factors. Penetration may be defined as joint penetration or root penetration.<sup>1</sup> Joint penetration is the minimum depth a groove weld extends from its face into a joint, exclusive of reinforcement (Fig. 1). Root penetration is defined as the depth a groove weld extends into the root of a joint measured on the centre line of the weld cross section (Fig. 1). In this work, only root penetration was measured

and the influence of the following four factors on this was considered: (a) shielding gas; (b) groove geometry; (c) root gap; and (d) heat input.

## Shielding Gas

The influence of shielding gas on root penetration obtained in Inconel 718 welds was investigated. Figure 2 shows typical cross sections through welds made under identical welding conditions except in one instance helium is the shielding gas and in the other argon. It shows clearly that welds made using helium have much improved penetration over those made with argon. (Quantitative measurements of root penetration are reported later.) This is because helium has a higher ionization potential than argon and hence produces a hotter arc.

## Groove Geometry

The influence of groove geometry on root penetration was investigated. A number of different V-grooves and also U-grooves were compared under the same welding conditions. Figure 3 shows typical cross sections through welds with different groove geome-

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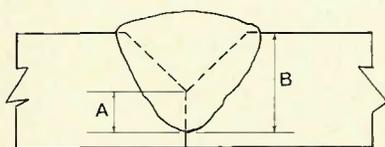


Fig. 1—Definition of root and joint penetration: A = root penetration; B = joint penetration

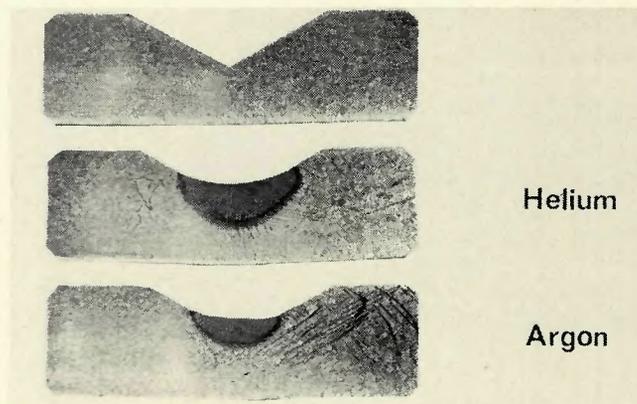


Fig. 2—Influence of shielding gas upon root penetration

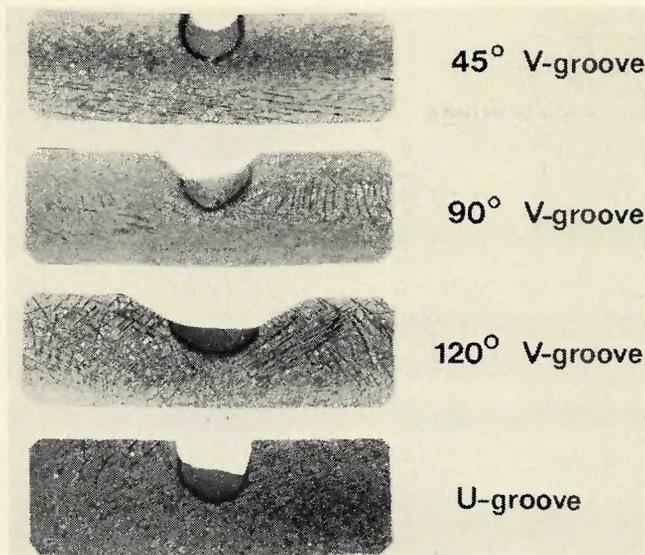


Fig. 3—Effect of groove preparation upon root penetration

tries. The examples shown represent welds made using the GTA process at a heat input of 30,000 joules/inch with argon shielding gas. Measurements of root penetration were made and its variation with groove preparation is shown diagrammatically in Fig. 4 along with the cross sectional area of the weld bead and the weld bead width. The influence of shielding gas is also shown.

Figure 4 clearly shows that the U-groove geometry gives the best root penetration on welding. This presumably is because it is possible to concentrate the molten puddle at the bottom of the groove to obtain penetration. There are disadvantages, however, in using this type of groove. It is expensive to machine and because the sides of the groove are nearly vertical the edge of the bead might not fuse into

the plate. This defect can be easily overlooked and for these reasons it is better, where possible, to use a V-groove. The results of Fig. 4 show that little real advantage is gained by using V-grooves having very wide angles. Little if any improvement in penetration is obtained. The effect is only to increase the width of the fusion zone, which is undesirable. The V-groove with an included angle of 90 deg gave the most satisfactory results. Narrower groove angles resulted in lack of penetration.

These tests were made under several conditions of weld heat input and very similar results were obtained. It was found that at higher heat inputs some improvement in penetration could be obtained by increasing the groove angle beyond 90 degrees.

#### Root Gap

The effect of root gap width on penetration was studied using a technique reported by Inagaki and Okada.<sup>2</sup> A specimen was used in which the root gap expands in the welding direction as shown in Fig. 5. Welds

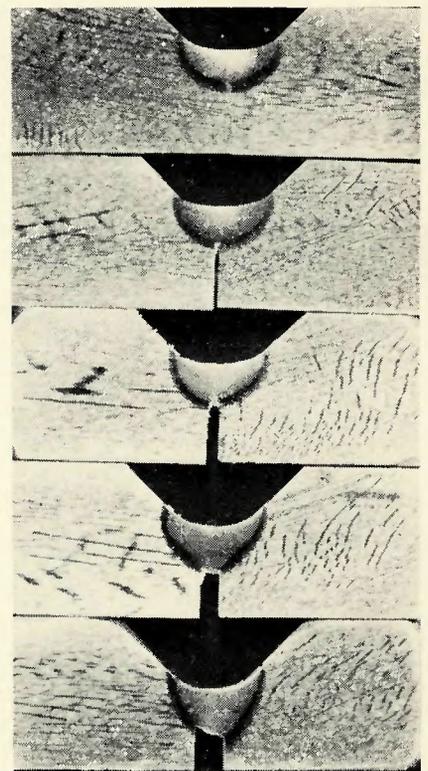


Fig. 6—Variation of root penetration with root gap width. Specimens welded by GTA process at 5000 joules/inch heat input with argon shielding

were made using the GTA process with a heat input of 5000 joules/inch. The specimen was then sectioned at intervals and the root penetration measured together with the cross sectional area and width of the weld bead. Figure 6 shows typical sections of welds on which these measurements were made and Fig. 7 shows the actual results. It is evident from Fig. 7 that the root gap width has an important influence upon penetration. Increasing the root gap width gave increased root penetration. There is of course a practical upper limit to the root gap width. It is of interest that the cross sectional area and width of

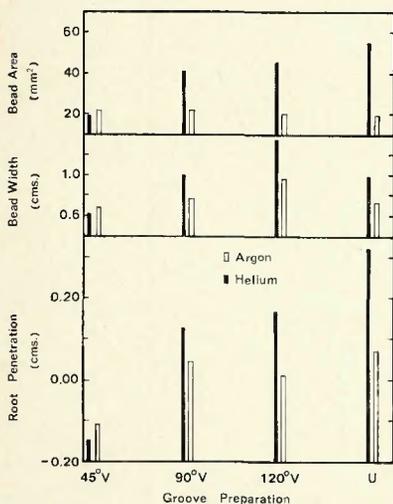


Fig. 4—Variation of root penetration, weld bead cross-sectional area, and weld bead width with groove preparation. Results are shown for both argon and helium shielding using a weld heat input of 30,000 joules/inch

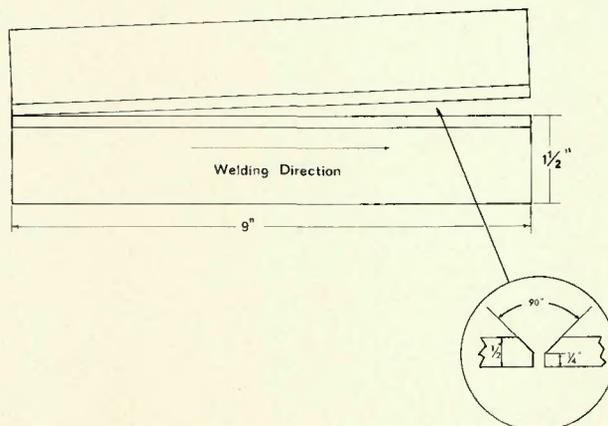


Fig. 5—Specimen design for varying root gap width

the weld bead were practically unaffected by the root gap width. It would therefore appear that increasing the root gap, to a limited extent, is an effective way of overcoming the poor penetration often encountered in the welding of nickel-base alloys.

### Heat Input

Increasing the heat input is the most direct way of overcoming poor penetration. Unfortunately it is not a very flexible control. There is a practical upper limit to increasing the heat input; beyond 30,000 joules/inch using the GTA process it was found almost impossible to deposit the root pass because "burn through" occurred. It was also found that the mechanical properties of the joint were inferior in welds made under conditions of high heat input.

### Microfissuring

Another problem encountered in welding Inconel 718 was microfissuring in heat affected zone. This has been recognized and investigated by other workers.<sup>3, 4, 5</sup> Essentially, microfissures are fine cracks, usually only 1 or 2 grains in length, that form in the heat affected zone of the weld adjacent to the fusion zone. These cracks are intergranular and seem to form along the boundaries of the

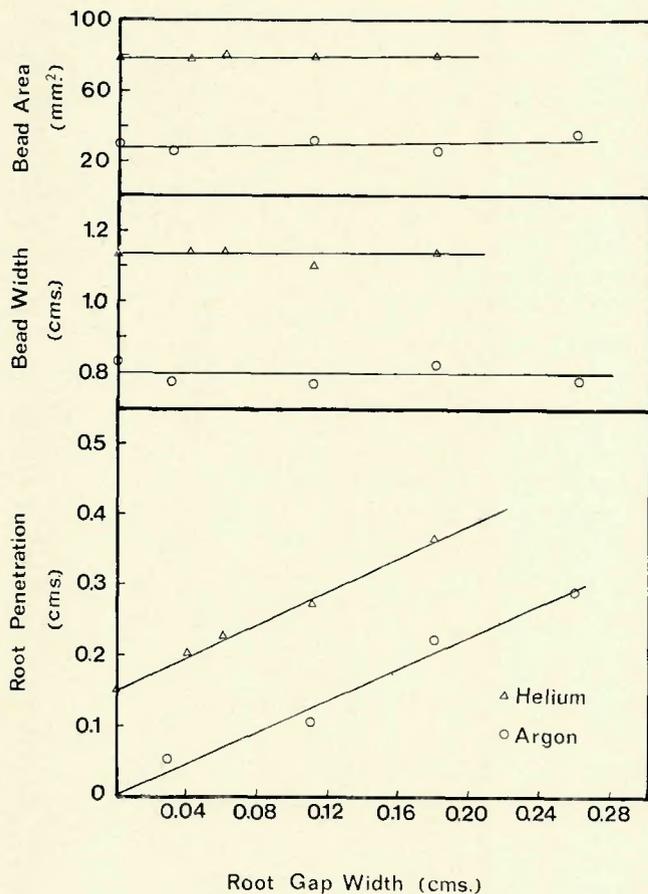


Fig. 7—Root penetration, weld bead cross-sectional area, and weld bead width as a function of root gap width. Welds were made at 5000 joules/inch heat input using both argon and helium shielding

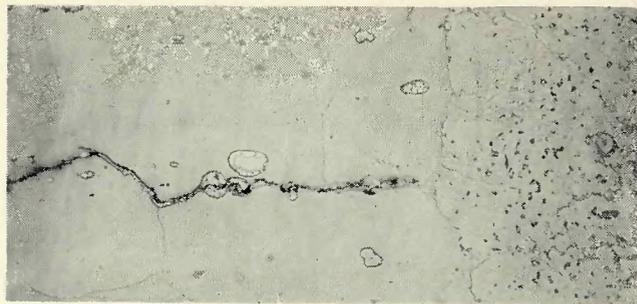


Fig. 8—Microfissure in Inconel 718 weldment. Magnification, 1000X

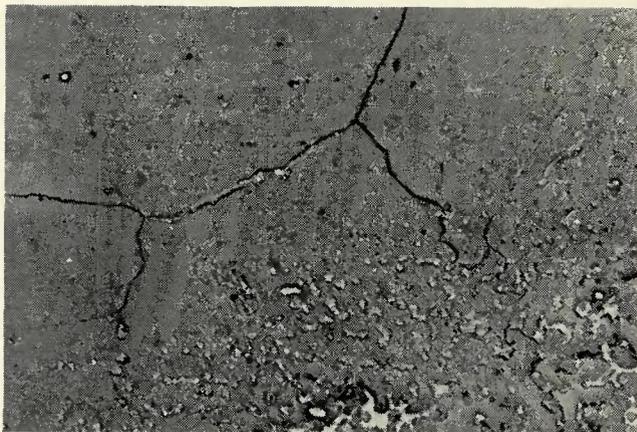
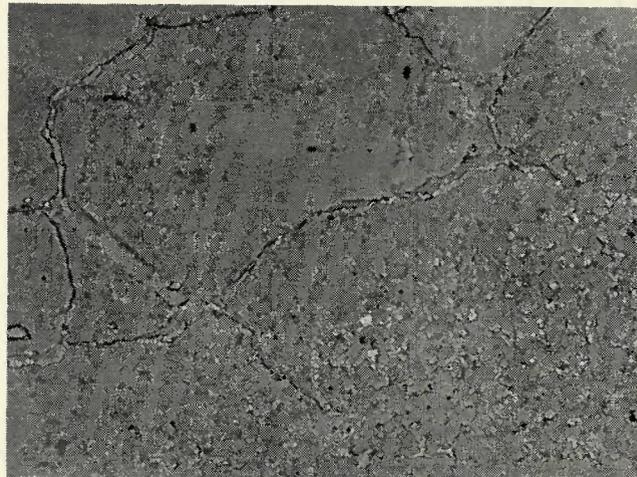
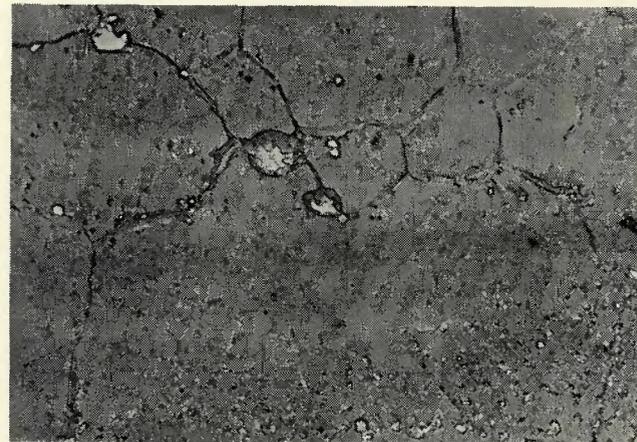


Fig. 9—Typical sections taken through bead-or-plate tests. (top) solution treated at 1700 F for 1 hr. X500. (middle) solution treated at 1900 F for 1 hr. X500. (bottom) solution treated at 2100 F for 1 hr. X500

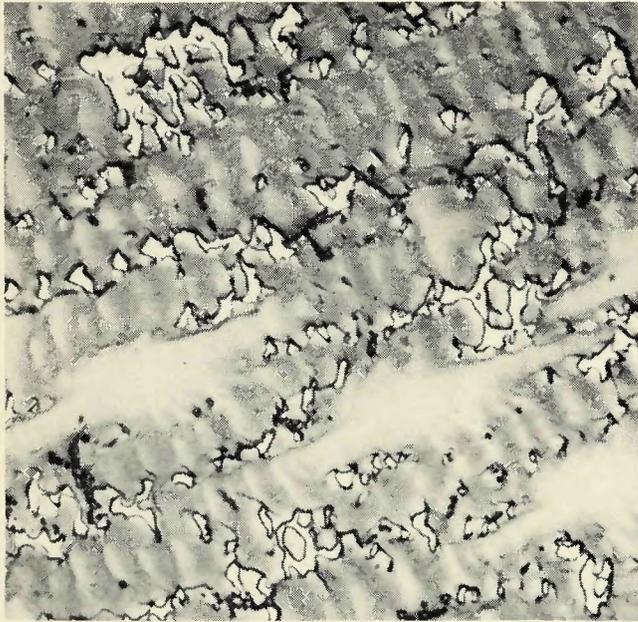


Fig. 10—Fusion zone of Inconel 718 weld showing white-etching Laves phase. X1000

partially melted grains close to the fusion zone. An example of a microfissure is shown in Figure 8. The effect of these microfissures on the mechanical properties of weldments has not been well established but, logically, they should be avoided. It was the purpose of this part of the work to find out how the problem could be minimized.

To evaluate the susceptibility of this particular heat of Inconel 718 to microfissuring, bead-on-plate tests followed by sectioning and metallographic examination were used. In this work it was found that the susceptibility of Inconel 718 to microfissuring in the heat affected zone was a function of two factors: (1) prior solution treatment temperature and (2) heat input on welding.

The solution treatment temperature before welding has an important influence upon microfissuring susceptibility. It was found after examination of a large number of specimens that material given high-temperature solution treatments before welding is more susceptible to microfissuring. Material that had been solution treated below 1900 F showed practically no incidence of microfissuring.

Figure 9 shows typical sections through bead-on-plate tests made on material, solution treated at 1700, 1900 and 2100F. All three show that grain boundary melting has occurred in the heat affected zones. However, the specimen solution treated at 2100 F shows evidence of cracking.

Electron probe micro-analysis of the grain boundary regions did not

reveal any noticeable differences in composition and the reason why material solution treated at 2100F should fissure along the grain boundaries has not been resolved. It would appear, from these results at least, that fissuring is not a direct result of grain boundary melting alone because this occurred in all three specimens.

The other factor which influences the susceptibility to microfissuring is the weld heat input. It was found that the susceptibility to microfissuring was greater under welding conditions of low heat input. It is clear that, to avoid microfissuring in the heat-affected zone of Inconel 718 welds, it is best to use low-temperature solution treatments (<1960F) before welding and to avoid the use of very low heat inputs during welding.

### Ductility of Weldments

A further problem encountered in the welding of Inconel 718 was development of adequate ductility in the weld. Table 1 shows typical mechanical properties of Inconel 718 welds for two different heat inputs and for the base metal.

Table 1—Mechanical Properties of Inconel 718 Weldments and Base Metal

Heat input joules/inch	Charpy impact strength ft-lb	Tensile strength psi	Yield strength psi	Elongation %	R. A. %
30,000	11.0	188,000	162,000	14.0	35.0
60,000	7.0	174,000	158,000	4.0	6.0
Base metal	25.0	198,000	165,000	23.0	44.0

Specimens solution treated at 1900F for 1 hour and then aged at 1325 F for 8 hours, furnace cooled to 1150F and aged 8 hours.

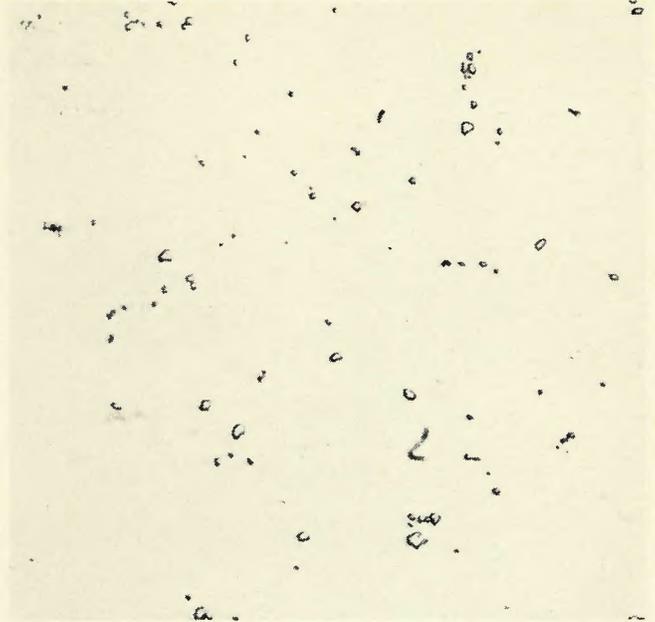


Fig. 11—Fusion zone of Inconel 718 weld, heat treated at 2000F for 1 hr and then aged. Dissolution of the Laves phase is almost complete and only traces remain in the structure. X1000

The results of Table 1 clearly show that the ductility and impact properties of the weldments were poor in comparison to the base metal. This is especially true for welds made with high heat inputs. The reasons for this were not immediately obvious and a metallographic study of the weldments was made to provide an explanation.

Figure 10 is a micrograph of the fusion zone. The white phase formed in the interdendritic regions of the weld metal was identified by its appearance and by electron probe microanalysis as the Laves phase, and it is this phase that is thought to be responsible for embrittlement that occurs in Inconel 718 weldments. Other workers<sup>6,7</sup> have reported the Laves phase can drastically reduce the ductility of castings but in welding it was previously thought that the rapid cooling rates that prevail would prevent the formation of this Laves phase.<sup>6</sup> This is clearly not so.

The elimination of the Laves phase from the weld fusion zone was achieved by heat treatment. By giving the weldment a high temperature solution treatment after welding it was

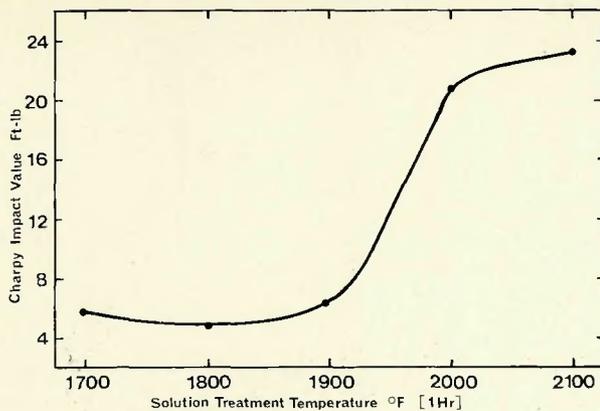


Fig. 12—Charpy impact strength of Inconel 718 welds as a function of post-weld solution treatment temperature

found the Laves phase can be largely dissolved, as shown in Fig. 11. The effect of a post-weld solution treatment on the impact strength of weldments is shown in Fig. 12. It is apparent that the impact strength of the weldment is improved considerably by using a high solution treatment temperature of about 2000 F. This improvement in impact strength coincides with the dissolution of the Laves phase from the fusion zone. Solution treatment temperatures below 1950 F have practically no effect on the Laves phase and result in little improvement in impact strength.

Similar results were obtained with tensile ductility, considerable improvements in ductility being achieved when giving weldments a post-weld solution treatment at 2000 F. Some reduction in tensile strength and yield strength in

the base metal occurs when using these high temperature heat treatments but in comparison to the benefits afforded, it is not of significance.<sup>8</sup>

### Summary

The results of this study have indicated that there are problems in welding Inconel 718 but that they can be overcome. The practical problem of obtaining good penetration can be solved by correct selection of shielding gas, root gap width and proper joint preparation. Microfissuring in the heat affected zone can be prevented by using material solution treated below 1950F and by avoiding low weld-heat inputs. Finally, the problem of obtaining adequate impact and ductility properties in the weld can be solved by using a high-temperature post-weld solution treatment (>1950F).

In general, the welding characteristics of Inconel 718 are good. The mechanical properties and particularly the stress corrosion properties are very good and it could prove to be a useful alloy for high strength marine applications.

### Acknowledgements

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