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Sealing of Al-Containing Stainless Steel
to Lithia-Alumina-Silica Glass-Ceramic

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ABSTRACT

Recent work carried out on a new glass-ceramic/alloy material set for the application of pyrotechnic components is discussed. A newly developed family of austenitic stainless steels has been hermetically sealed to a widely used lithia-alumina-silica (LAS) glass-ceramic. These alloys, originally developed for applications where high oxidation resistance is required, contain 4-5 wt% aluminum. The presence of aluminum offers several advantages from a glass or glass-ceramic sealing point of view. These include: the presence of a tenacious, stable oxide (Al_2O_3) on the alloys' surface as well as the fact that they can be strengthened during sealing via precipitation of a secondary phase, $NiAl$. In addition, these alloys offer lower material and machining costs, and improved weldability when compared to the widely used Ni-based superalloys.

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INTRODUCTION

The manufacture of pyrotechnic components requires the hermetic sealing of one or more metallic alloys to an electrically insulating material, such as a glass or a polycrystalline ceramic. At Mound, over the past seven years, the materials of choice have been a phosphate-nucleated lithia-alumina-silica (LAS) glass-ceramic and two nickel-based superalloys, Inconel-718* and Hastelloy C-276**. During manufacture, an amorphous glass preform is heat-treated to allow for melting and bonding to the metallic alloys and to achieve the proper thermal expansion properties to match the alloys. This fabrication method offers several advantages over the more conventional glass or ceramic to metal seals. The flow properties of the glass allow for rather intricate geometries to be readily achieved and the toughening properties of the ceramic allow for the attainment of twice the strength of the present glass. Additionally, the heating process in sealing a metal to a LAS glass-ceramic is much less time consuming than the conventional ceramic to metal sealing process of metallizing and brazing. In the former, the seal occurs during a single, low-temperature firing, while in the metallizing/brazing several high temperature steps are oftentimes required. The glass-ceramic/metal seal process, in combination with shell design, can result in components which are able to withstand over 100,000 psi explosive pressure.⁽¹⁾

The success of the glass-ceramic/nickel-based alloy system has led to the development of other material sets which are applicable in pyrotechnic components. More specifically, lower strength applications need to be addressed. In addition, it is desired to improve upon the weldability of the Ni-based alloys, where a filler material is now being used to prevent cracking, as well as to lower the material and machining costs associated with these materials.

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EXPERIMENTAL

In the examination of any new alloy for the purpose of sealing to a glass or glass-ceramic, several properties are important. This work is concerned with the following properties as they pertain to two Al-containing alloys, alloy 896 and 899. They are: thermal expansion, yield strength, weldability, wettability of the glass on the metal, and bond strength between the glass and the metal. (2,3)

The coefficients of thermal expansion (CTE's) were determined with a Theta dual pushrod dilatometer. Samples were heated at $8^{\circ}\text{C}/\text{min}$ and single crystal sapphire was used as a reference material.

Yield strengths were determined by ASTM Test C-8. Bead-on-plate welds were made with a Raytheon model SS-501-7, 400 watt Laser which had the following parameters: 130 watts weld power, 15 Hz pulse rate, 5 ms pulse time, 20 cm/min travel, argon shielding, 80% pulse overlap and approx 3 mm weld thickness.

The burst strength between the glass and the metal alloy was measured in this study by sealing the glass into a test header and determining the force necessary to shear the glass-ceramic plug out of the shell. The actual bond strength was then calculated by dividing the the force to yield by the glass/metal contact area. Metal shells were made of Inconel 718 and of alloy 896. Two different shell wall thicknesses were also studied; they were 0.035" and 0.050".

RESULTS AND DISCUSSION

During manufacture, an amorphous LAS pre-form is heat-treated (Figure 1) to allow the growth of lithium metasilicate, lithium disilicate, and the high expansion phase, cristoballite. The result is a hermetically sealed unit with a glass-ceramic with twice the strength of the parent glass, and overall components, such as those pictured in Figure 2, able to contain > 100,000 psi explosive pressure.

Results of CTE determinations are shown in Figure 3. As can be seen, both alloys 899 and 896 are relatively high in expansion, comparable to the other austenitic alloy, 304L. However, it can be seen that both of the Al-containing alloys are more closely matched to the presently used LAS-glass than is 304L. The "hump" seen in the LAS-glass curve around 200-300°C is indicative of the alpha-beta cristoballite phase inversion which takes place.

The strength of an alloy is important, particularly the yield strength which will determine when the alloy will fail upon the firing of the pyrotechnic component. Furthermore, it is the 'post-sealed' yield strength that is important, rather than the as-received value, especially when the insulator material is a glass-ceramic which requires a controlled heat treatment, such as that shown in Figure 1. Figure 4 contains both the as-received and post-sealed values for the various alloys tested. As can be seen, the Al-containing alloy, 896, has an increase in strength following the heat treatment, whereas 304L is actually weakened during sealing. For comparative purposes, Inconel-718 is also shown. This nickel-based alloy has a post-sealed strength of over 120 ksi.

Figure 5 contains two optical micrographs which were taken of a polished sample of as-received and post-sealed Alloy 896. The micrographs show that the post-sealed sample exhibited an increase in the secondary phase (dark phase at the grain boundaries) than does the as-received sample. This phase, which has been identified as NiAl via wavelength dispersive spectroscopy (WDS), is the reason that the post-sealed sample exhibited the higher strength displayed in Figure 4. Essentially, the alloy is being toughened during sealing to the glass by precipitation hardening, similar to Inconel-718 which is hardened by Ni₃Nb precipitation.

During manufacture, the metal shells of actuators often need to be welded. This requirement can be achieved without affecting the explosive charge by making small welds with a pulsed laser. Figure 6 illustrates the optical microscopy of a pulsed Nd:YAG laser welded

Al-containing 899 alloy and the results show no evidence of hot cracking.

The bond strength results are shown in Figure 7 and indicate that the thicker walled 896 samples yielded a greater bond strength because of the higher thermal expansion of the Al-containing alloys. It should be noted that no evidence of cracking or separation between the glass and metal was seen because of this higher compressive stress in these alloys.

CONCLUSION

The initial examination of Al-containing stainless steel alloys for use in pyrotechnic components has been completed. Results indicate that these alloys are comparable to the presently-used nickel-based alloys from a bond-strength point-of-view and can be hermetically sealed to the widely used lithia-alumina-silica (LAS) glass-ceramic. Additionally, these alloys offer a lower material cost when compared to the nickel-based superalloys as well as improved weldability properties.

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**YIELD
STRENGTH
(KSI)**

ALLOY

5(a)

5(b)

**BOND
STRENGTH
(PSI)**

ALLOY AND WALL THICKNESS