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FEASIBILITY STUDY ON THE
DIFFUSION BONDING OF URANIUM

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FEASIBILITY STUDY
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I INTRODUCTION

Uranium is a highly reactive metal, and combines readily with many metallic and non-metallic elements.

Its tensile properties after being beta heat treated are as follows:

Ultimate Strength:	60-85,000 PSI
Yield Strength:	30-35,000 PSI
Elongation In 2":	7-10%
Reduction In Area:	12%

The material used in this program was D-33 wrought uranium, selected so as not to exceed the following impurity levels:

Mo	-	5 PPM	Al	-	15 PPM
Ni	-	25 "	Ca	-	50 "
Si	-	17 "	Fe	-	75 "
Mn	-	35 "	C	-	45 "

The specific chemical and physical properties of this particular uranium composition are classified.

The joining of uranium, either by welding or by brazing, is difficult because of the metal's reaction with the atmosphere. In addition, uranium forms brittle compounds with many of the dissimilar metals which might otherwise be considered suitable for use as brazing filler metals.

Protective plating of uranium with nickel or silver prior to brazing has shown some promise; however it appears that extremely high purity inert gas atmospheres, or high vacuums, on the order of 10^{-4} to 10^{-7} mm Hg should provide the optimum avenue of approach to protecting the metal during the development of satisfactory joining techniques.

Because of its high reactivity with other elements, uranium should have good potential for solid state diffusion bonding and for catalyst diffusion bonding.

In recent times, diffusion bonding has received increased attention as a method of obtaining joint strengths that are within the range of the strengths of the base materials themselves. In addition, where unusual metals and alloys, such as uranium, titanium, and zirconium, have strong tendencies toward interfacial embrittlement when brazed with many of the common filler metals, diffusion bonding is a method of retaining the ductility of the base metal in the joint area without sacrificing joint strength.

Basically, the requirements for diffusion bonding are to bring the mating surfaces into intimate contact so that their interatomic attractive forces can become effective, and to apply sufficiently high temperatures to open up the lattice and increase the mobility of the metal atoms to the point where interchange, or movement of the atoms occurs across the bond interface. In catalyst diffusion bonding, where a thin intermediate dissimilar metal layer is used to "activate" diffusion, the catalyst film has the ability to "clean" up the interface, and to fill surface discontinuities so that more complete contact is established between the base metals, and greater and more uniform atomic interaction can occur. Since the major effect of high pressures is also to establish more complete interfacial contact (diffusion cannot occur across an interface in areas where the metals being joined are not in intimate contact), it follows that "catalyst" diffusion bonding has the effect of reducing the pressures required on the joint and in many instances, reducing the temperatures required to effect sound bonding.

Another type of diffusion bonding, termed "eutectic" or "semi-diffusion" bonding, utilizes a thin intermediate film of another metal which is known to form lower melting alloys, or eutectics, with the base metals. In this type of bonding, a solid state diffusion reaction occurs first between the catalyst film and the base metals, forming a lower melting alloy in the joint. This alloy then melts and flows through the joint, effecting an ordinary brazed bond.

II OBJECTIVE

The objective of this study is to determine the feasibility of effecting diffusion bonding in uranium, using pure gold as a "catalyst," and by solid state diffusion without the use of a catalyst.

III RESULTS AND RECOMMENDATIONS

As a result of the preliminary metallurgical study portion of this program, it was found that the gold appeared to have promising characteristics for catalyzing the diffusion bonding reaction in joining uranium to itself. Other unknown factors are involved, however, that can only be resolved by experimental work in the actual diffusion bonding of uranium.

Studies of the alloying characteristics of metals other than gold indicate that there are other promising elements for backup investigations if gold, for some reason, should prove unsatisfactory.

It is recommended that this program be continued into the experimental diffusion bonding phase, investigating the use of those catalyst metals which this preliminary study indicated may have promise in developing techniques for diffusion bonding of uranium.

IV MATERIALS

Type D-38 wrought uranium tubing

Pure gold.

V EQUIPMENT

This work was scheduled to be done in a high vacuum induction heating device in the vacuum range of 10^{-6} to 10^{-7} mm Hg, using a diffusion bonding temperature range of 1580 to 1600°F.

VI METHOD OF APPROACH

The program was divided into two phases.

Phase I consisted of studies of catalyst-diffusion bonding using pure gold as the catalyst layer.

Binary phase diagram data on the gold-uranium alloying system indicated that at 85.3 weight percent of gold in uranium, an eutectic alloy is formed with a melting point of 1625°F, which is considerably

below the melting points of either gold (1945°F) or uranium (2071°F). The research in this phase would involve investigations of time temperature, pressure and catalyst thickness parameters required to effect sound diffusion-type bonds in wrought uranium specimens.

Phase II consisted of studies involving the solid state diffusion bonding of uranium to itself without the aid of catalyst films.

This phase would involve the investigation of surface preparations, applied pressures, time, temperatures, and related parameters to develop a technique for producing reliable solid state diffusion bonds in uranium. Advantage would be taken of the reactivity and diffusion rates of uranium in an effort to direct these characteristics along the lines necessary to perform solid state diffusion.

Although this study was confined to solid state diffusion bonding and catalyst diffusion bonding with gold as the catalyst, other thin films applied to the interfaces, such as chromium, cobalt, copper, iron, manganese, nickel, and vanadium, should also be investigated because of their tendencies to form lower melting eutectics with uranium.

In general, when metals diffuse, the greater the melting point of the liquid or molten phase, the smaller the diffusion constant becomes. Further, the diffusion constant depends inversely upon the solid solubility of the metals involved, being least for metals which form a continuous series of mixed crystals. The additional energy needed to loosen the lattice sufficiently for diffusion to occur is less for dissimilar than for similar atoms; however the entropy for activation is greater for similar than for dissimilar atoms. Thus, the energy required for loosening the lattice and causing increased rates of diffusion is to a large extent, temperature dependent.

Binary constitutional diagrams for alloying of uranium with selected catalyst metals beginning with gold (Figure 1), illustrate the low melting alloy combinations for catalyst-uranium systems which provide liquid phases (the compositions of which are determined by solid state diffusion) which might further accelerate diffusion into the uranium base metal.

Some of these catalyst metals, especially gold, cobalt, and manganese, have high neutron absorption characteristics. These

metals may or may not be detrimental, since they are used in extremely thin films and, in many instances, will be diffused away from the bond after a joint is effected, resulting in very low concentrations spread out in the uranium.

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FIGURE 1

GOLD-URANIUM

There are two low melting eutectics which can be formed in this system, one at 3.9 weight percent of gold (1931°F), and the other at 85.3 weight percent gold (1571°F). The limit of solid solubility of gold in uranium is 2.7 weight percent at 1931°F. There is negligible solubility of uranium in gold.

FIGURE 2

URANIUM-CHROMIUM

Only one known low melting eutectic is formed in this system at 5.19 weight percent chromium (1578°F). The limit of solid solubility of chromium in uranium is approximately 1 weight percent at 1578°F.

FIGURE 3

URANIUM-COBALT

The uranium-cobalt system indicates the possibility of forming two low melting eutectics, one at approximately 6.26 weight percent of cobalt, (1354°F), and the other at approximately 60.0 weight percent cobalt (1945°F). There appears to be no solid solubility range for cobalt in uranium.

FIGURE 4

URANIUM-COPPER

Two low melting eutectics are observed in this system, one at approximately 1.57 weight percent copper (1976°F) and the other at approximately 30% copper (1742°F). This system shows no solid solubility of copper in uranium.

FIGURE 5

URANIUM-IRON

There are two low melting eutectics observed in this system, one at approximately 9 weight percent iron (1375°F), and one at approximately 55 weight percent iron. Only a slight degree of solid solubility is indicated in the temperature range of 1418°F to 2057°F.

FIGURE 6

URANIUM-MANGANESE

Two low melting eutectics are observed in this system; one at approximately 6 weight percent manganese (1321°F), and the other at approximately 55 weight percent manganese (1895°F). Solid solubility is shown on the high uranium side to a maximum of approximately 1 weight percent of manganese at a temperature of 1339°F.

FIGURE 7

URANIUM-NICKEL

Two low melting eutectics are observed in this system, one at approximately 12.0 weight percent nickel (1360°F), and the other at approximately 70 weight percent nickel (2015°F). The solid solubility of nickel in uranium is indicated as being negligible.