SLAC-TN-67-5

U. Cummings

This is an internal informal note not to be abstracted, quoted or further disclosed without approval of the author.

A SURVEY OF ALUMINUM TO STAINLESS STEEL TRANSITION TECHNIQUES

Urban K. Cummings Stanford Linear Accelerator Center Stanford University, Stanford, California

ABSTRACT

A comprehensive survey is made of current methods for joining aluminum alloys to austenitic stainless steels. With several exceptions the scope is limited to those techniques which are potentially suitable for all-metal ultra-high vacuum applications. Commercially available transitions are described as well as some techniques which have been successful in various space and military applications but are not on the market. Evaluation of the methods described is limited to several techniques which appear suitable for application to the colliding beam storage ring proposed by the Stanford Linear Accelerator Center.

I. INTRODUCTION

The vacuum chamber for the proposed electron positron colliding beam storage ring at $SLAC^1$ will be constructed of extruded 6061-T6 aluminum alloy. The design parameters which dictate the chamber configuration suggest the use of an extruded section. The choice of aluminum was dictated by its dependable extrudability, low electron desorption coefficient² high synchrotron radiation absorption and high thermal conductivity. The latter property permits the water-cooled radiation absorber to become an integral part of the extrusion rather than a separate body inserted into the chamber. The shape of the chamber passing through the bending magnets is rectangular; that passing through the remaining portion is circular. The rf cavities are fabricated of aluminum.

II. REQUIREMENTS

Development of reliable ultra-high vacuum transition sections for use between the aluminum chamber and such stainless steel appurtenances as ion pumps, view ports, bellows, expansion joints, high voltage insulators, etc., is of prime importance.

III. SCOPE

Only those transition techniques which possess long term dependability for ultra-high vacuum applications would be acceptable. Specifically they must maintain vacuum integrity (leak rate $< 2 \times 10^{-10}$ std cc's per sec He) while withstanding repeated bakeout cycles at temperatures above 200°C in the presence of a moderate field of ionization radiation. Hydrocarbon contamination causes significant increases in the electron desorption coefficients. Therefore the obvious

-2-

elastomer gasketed joint between aluminum and stainless steel flanges is not suitable. Although Viton* compounds have been known to withstand 200°C bakeout³ and display some radiation resistance,⁴ the presence of hydrocarbon contamination associated with such polymers cannot be tolerated in the vacuum chamber.

The possibility of using a Polyimide^{**} material as reported by Hait³ is under consideration. Although Polyimide appears capable of 300[°] C bakeout and probably possesses the greatest radiation resistance of any available synthetic, its uncertain desorption characteristics require a careful systematic evaluation.

This note reports on the search for an all-metal transition. Some of the methods given are all-metal junctions possessing suitable leakage reliability but not capable of withstanding the required bakeout temperature. They are not under consideration and are reported here for information purposes only. Many of the processes described have been used to join a wide variety of metal combinations. It is the purpose of this technical note to disclose these processes as they apply particularly to aluminum-to-stainless steel junctions. Their application to other metal transitions has been omitted in most cases.

IV. CATEGORIES

Transition sections can be classified by either the scheme used to join them, such as bonding or brazing, or by their functions, such as separable or inseparable. Both must be considered for use on the storage ring because certain items as ion pumps and view ports must be detached periodically. If the aluminum-tostainless steel interface can be provided at the flanged junction, cost can be reduced

-3-

T.M. Reg. I.E. DuPont

^{**} T.M. Reg. I.E. DuPont

from that which would require flanges plus a transition piece. For this reason the various methods will be grouped as separable or inseparable. Further groupings will be made in two cases where the techniques are basically identical.

V. INSEPARABLE JUNCTIONS

A. Clad Metals

Recent advances in metal-to-metal layering⁶ and cladding⁷ techniques have made it possible to assemble an integral structure of fundamentally different metals heretofore not joinable.

The automotive, construction, and consumer goods industries have created a demand for veneered metals. For reasons of environmental protection, cost economy, weight savings or ornamental use, most of the widely used ferrous and nonferrous metals have now been joined to one another by cladding. The majority of these composites are made in either sheet or strip form. The cladding can be accomplished by mechanical bonding, electrochemical or electroless chemical deposition, or by vapor or vacuum deposition techniques. By shaping these materials into the required configuration and selectively removing the clad metal from the base metal (either before or after shaping) one can form a transition of intimate bond between metals which are difficult to join by conventional welding or brazing techniques.

1. Roll Bonding

The major quantity of mechanically joined cladsheet stock is produced by roll bonding. An adherent bond is formed between the metal layers by the high pressure (25 to 50 KPSI) and moderate temperatures (700° to 900° F) which accompany the rolling process. A 10% reduction in thickness is normal. Carefully controlled preparation of the mating surfaces by chemical treatment is an obvious necessity.

-4-

The exact procedures involved are proprietary except that some fabricators admit to using 1100 or 1145 alloy cladding on the side of the aluminum sheet which faces the stainless steel. The preferred base aluminum alloy is 3003 or 3004. Type 304 stainless steel is used because of its low cost and availability. Other austenitic alloys could be used with equal success.

Three manufacturers of roll-bonded stock were located. There may be others. A pioneer of these clad materials is Metals and Controls, Inc., ^(a) an old-timer in making bi-metallic strips for thermostats. They will bond any 200, 300 or 400 series stainless steel to 3003 or 1100 alloy aluminum of a thickness ratio up to 50/50 for a total thickness of 0.040 inch to 0.130 inch in strips up to 16 inches in width. The stainless steel is in annealed condition, the aluminum is 1/2 hard, or can be supplied annealed. They stated they can bond also to 2024 aluminum alloy but not to 6061.

The group at SLAC planning the storage ring facility acquired some of this material for evaluation. The 304 stainless steel is 0.025 inch thick; the 3004 aluminum 0.060 inch. It was hydroformed into 3-inch diameter cups about 2-1/4 inches deep. The bottom of the cup was removed and the aluminum etched off of the stainless steel 1/2 inch from one end. On the other end, 1/2 inch of the stainless steel 1/2 inch from one end. On the other end, 1/2 inch of the stainless steel was machined off of the aluminum. These steps are illustrated in Fig. 1. The result is a tubular transition to which each metal tube can then be welded. Over a dozen of these were made and tested. The 3004 alloy was welded to a 6061 aluminum pumpout tubulation using 4043 filler rod. The stainless steel end was sealed off with a cap plate by tungsten inert gas (TIG) fusion weld. Three of these cups were baked out at temperatures from 200° to 300° C for up to 72 hours with no detectable leak greater than the 2×10^{-10} std cc's/sec Helium sensitivity of the leak detector. The width of the overlapping band of aluminum-to-stainless steel ranged from 1/2 inch (a) Letter references: See Appendix "Manufacturers' Names and Addresses."

- 5 -





to 1-1/2 inches on various samples. Metallographic examination of the aluminumto-stainless steel interface revealed no evidence of intermetallic diffusion. The materials apparently are bonded by the adherent forces of intimate contact without intermediate chemical reaction. The manufacturer states that no interstitial material was used between the two metals. From the results of our tests it would appear that this scheme would be satisfactory for use on the proposed storage ring. The principal limitation of this method is that of maximum diameter and depth of cup that can be formed from available widths. Except for samples, orders of this material require a mill run of 1000 lbs. minimum.

Aluminum Company of America $(ALCOA)^{(b)}$ is another supplier of roll-bonded aluminum-to-stainless steel. It is marketed as "Duranel"⁸ by their Wearever Division and was developed for use in pots, pans and other cooking utensils. For this use, the stainless steel is 0.009 to 0.010 inch thick on 0.060-inch to 0.100inch aluminum. This can be obtained without a mill quantity run and is available in widths greater than 15 inches. The thin gauge of the stainless steel does limit the freedom of joint design for TIG welding.

The third source for roll-bonded stock is Composite Metals, Inc.^(C) They imposed no restrictions on the quantity of the initial order or the range of thicknesses to be joined. Four pieces 18 inches square were obtained. The price is about \$2.50 per pound, composed of 0.105 inch thick 3004 aluminum (preclad with a thin veneer of 1145 alloy) and 0.045 inch thick 304 stainless steel. They claim peel strengths of the junction greater than the yield strength of the aluminum. These samples have not yet been tested.

2. Static Bonding

Another mechanical bonding method is described in a 1959 patent⁹ assigned to ALCOA. In this process the bond between metals is made by what the inventor calls "static hot pressing." The aluminum is forced to adhere to the stainless

- 6 -

steel by means of applying a temperature and pressure which exceeds the yield point of the aluminum, thereby causing a swaging action. It was developed for the purpose of applying stainless steel cladding to the sole plates of hand irons, the advantage being the sole plate was aluminum cast with the heating element imbedded in it. This forging process might be applied to fabricating transitions by the use of wrought aluminum. It would permit a wider variety of shapes to be formed than those which are limited by techniques of shaping sheet material.

B. Warm Welding

The work described by Batzer and Bunshah¹⁰ which they have named "Warm Welding" is worthy of mention. Although they did not test aluminum-stainless steel combinations, such a junction may be possible.

Their combined process of 2-step surface cleaning conducted in ultra-high vacuum, plus the prolonged applied pressure at elevated temperature, makes possible a structured bond between the two metals being joined. Batzer's³⁰ experience with aluminum foil gasketed high-vacuum flanges (see Section VI-A) indicates warm-welding of aluminum to stainless steel is practical. Stainless steel UHV flanges joined with an aluminum foil gasket and baked for 30 hours at 400° C at high vacuum and with high gasket loading required a wedge to pry them apart. After separation, much of the aluminum had to be scraped from the flanges. Batzer suggests that the aluminum oxide is dissolved <u>in</u> the aluminum under this environment, thereby permitting a diffusion type bond between the metals.

C. Aluminum Deposition Methods

A third method of cladding metals is by high-rate deposition of aluminum vapors.

1. Vacuum Evaporation

A pioneer in this field has been Temescal Metallurgical Corporation.^(d) Although there is a dearth of detailed information available, in general it is simply

-7-

a scaled-up version of the same electron beam techniques used in <u>thin film</u> vacuum evaporation. Film thicknesses in the order of inches can be applied to substrates by the use of electron beam melting¹¹ and the 50-kW power supplies now available. Aluminum has been deposited from these sources at rates of 1 to 2 lbs/hr.¹² Food container and automotive muffler applications are making use of vapor deposited aluminum on steel. Normally a diffusion barrier of titanium is applied to the steel before depositing the aluminum. Stainless steel sheet stock clad with evaporated aluminum would probably not be competitive with mechanically bonded layered metals. It does offer many possibilities of depositing aluminum onto shapes for subsequent welding or brazing to aluminum as transitions. For more on vacuum evaporated coatings, see Section V.K.4 of this report.

2. Vapor Deposited

Vapor deposited coatings are distinct from vacuum evaporated in that they are normally performed at atmospheric pressure. The Aluminum Alkyl Vapor Deposition Process¹³ has been a laboratory technique for producing pore-free high-purity (99.99%) aluminum coatings on any substrate that can be heated to 356° F. General Technologies Corporation^(e) has developed a commercial-scale capability utilizing this process for batch or continuous coating. Deposition rates on the order of .5 mil per minute have been achieved on a wide variety of shapes.

In response to a SLAC request, the producer offered to coat sample copper strips with a .020-inch thick deposit of aluminum on a best-effort basis at \$125/day. No inquiry was made regarding stainless-to-aluminum transitions.

D. Molten Dip Processes

Several other methods have been used for transitions by precoating the steel prior to welding to the aluminum. Miller, ¹⁴ and Miller and Mason¹⁵ describe hot-dipping 304 stainless steel in 1100 aluminum alloy at 1300[°] F or rub-coating

- 8 -

with 718 aluminum alloy. Finke and Begerman¹⁶ hot-dipped steel in pure aluminum and in aluminum containing 8.5% silicon. The silicon alloy produced a thinner iron-aluminide diffusion zone.

Richard Cole at A. D. Little, ^(f) has described a similar dip process ¹⁷ which he and others have used for making transitions up to 4 inches in diameter in certain cryogenic apparatus. One to two mils thickness of aluminum is accumulated on the stainless steel tube by dipping it in flux sprinkled molten 1100 aluminum. After cooling, an aluminum tube is forced over part of the aluminum coating and TIG welded to it using 4043 alloy filler. This junction withstands thermal cycling from ambient to 20^{0} K.

E. Diffusion Bonding

A report by Crane <u>et al.</u>,¹⁸ of the Boeing Company describes the development of a diffusion bonding process joining 2219 or 6061 aluminum to 321 stainless steel. This document also reports their tests of welding and brazing of several aluminum and stainless steel alloys. It also contains an excellent bibliography on joining aluminum to stainless steels. Briefly, the process is as follows:

On 8-inch and 20-inch diameter sample tubes, a diffusion barrier of silver is electro-deposited onto both the i.d. of the aluminum ring and the o.d. of the stainless steel ring in the area of mutual contact. The outer aluminum ring is expanded by heating and the inner stainless ring shrunk by immersing in liquid nitrogen. They are inserted and equalized to room temperature. Machined clearances were chosen to optimize the hoop stress caused by differential thermal expansion. The assembly is then soaked 2 to 4 hours in an air furace at 400° F to 600° F to accelerate the diffusion bonding process. In tests, shear strengths of 15 to 20 KSI are attained. Specimens are subjected to test at -320° F and -423° F but not at elevated temperature since they were intended for cryogenic application. Parts were reported tested with helium leak detector but no quantitative results given. These junctions

- 9 -

were developed for use by NASA but are not being marketed by Boeing. The process could be applied to noncircular sections with the use of a platen press.

For the person interested in stainless steel-to-aluminum transitions, this Boeing report is a most comprehensive document covering many approaches to transitions.

F. Tandem Extrusion

Nuclear Metals, Inc., ^(g) has developed a highly reliable but relatively expensive transition by a novel method called "tandem tubular extrusion."¹⁹ The process involved is approximately as follows: Cylinders of aluminum and stainless steel, slightly over-size and shorter than the required size of the finished part, are placed end to end in a mild steel container, welded shut, pumped out and sealed. This cartridge is then forced through extrusion dies. In so doing, an intimate tapered junction is formed between the two inner pieces. The outer shell is next machined off and finally the o.d. turned and the i.d. bored to the dimensions desired.

These units are available in 304 stainless steel to 6061 aluminum alloy in diameters up to 4 inches. The manufacturer states they could be made as large as 6 to 8 inches in diameter. They claim leak integrity to 1×10^{-9} cc's/sec and bond strengths of over 40 KPSI at room temperature. Strips cut from the junction and tensile-tested always fail in the aluminum, not in the bond. Prices range from \$125 up to \$900, depending on size and quantity ordered.

G. Fricton Welded

Paul Gripshover²⁰ at Battelle Memorial Institute is developing the use of spinfriction welding for joining dissimilar metals. Most of the work has been done so far in the zircalloy, hastalloy, inconel/incalloy series. Test joints on aluminumto-stainless steel indicate they are not difficult to join by this process. By rotating one component at low speed and high torque and bringing the other component up to

- 10 -

it with careful control of such parameters as joint temperature, time and torque, a fine-grained, diffusionless bond with high impact strength can be achieved. Gripshover is making test junctions in 304 stainless steel to 6061 aluminum 10-inch pipe for evaluation. Lawrence Radiation Laboratory in Livermore has obtained one of these machines. It is capable of 10,000-pound axial thrust. American Machine and Foundry Company utilizes this same technique for joining steel gears for the automotive industry.²¹

Gatzek²² has also reported satisfactory results in friction-welding 1-inch o.d. \times 0.25-inch wall 6061 aluminum to 304 stainless steel.

Tube Turns, Inc., ^(h) markets an inseparable bolted flange transition from 304 stainless steel to 5083 aluminum which they say is "jointed together by cold pressure welding to produce a strong, ductile, solid phase bond." Their tests include thermal cycling 212° F to -320° F, and helium leak tests to 1×10^{-9} atm cc's/sec. They are made in 4-1/2-inch o.d. to 16-inch o.d. sizes. From the description, one might guess they are friction welded.

H. Electron Beam Welded

Electrofusion Inc.⁽ⁱ⁾ has joined 1-1/2-inch diameter aluminum and stainless steel tubes using electron beam welding techniques. A 1/16-inch wide silver intermediary was placed at the junction between the tubes. The bond is made by fusing the aluminum and stainless steel components to the silver and not to each oth ϵ The work was performed for Applied Radiation Co.^(j) The parts were leak tight mass spectrometer helium leak test. No mechanical tests were performed. We obtained several samples sectioned from both weld areas of one of the tubes. Inspection after mounting and polishing revealed a very narrow

- 11 -

fusion area indicating good control of the beam spot size. No signs of porosity or other inhomogeneity were detected. It was a full penetration weld thoughout most of the specimens examined.

The mechanical properties of such a junction should be analyzed. The advantages of this method are the lack of surface contamination achievable in the vacuum environment and the freedom of joint design.

I. Flash Welded

A trimetallic junction of 304L stainless steel to 1100-H18 aluminum using a copper interface has been developed by C. E. $Burley^{23}$ of Reynolds Metals Co. for cryogenic applications. Over 100 samples in 1-inch pipe size were made by Thompson Electric Welder Co.^(k) using their model F4 (250 KVD) flash welder. The only surface preparation used was to square the ends of the tubes to be joined. A fixture is required to bring the parts together axially as the voltage is applied. A 1/2-inch long OFHC copper section is first flash-welded to the stainless steel. The aluminum-to-copper weld is made last. Tests using Monel or nickel at the interface were less satisfactory.

Forty-five out of the 62 junctions made with copper were leak-tested with a helium mass spectrometer. No leaks were detected before or after 10 thermocycles from 150° F to -320° F. Leak detector sensitivity was $< 1 \times 10^{-10}$ std cc's/sec per division. Ultimate tensile tests at room temperature and -320° F were 10, 190 lbs and 9, 680 lbs, respectively. The weld flash was removed before tests began. These units are not available off the shelf but will be made by Thompson on order. Two inches is the largest size presently made. Four inches is the maximum that could be made with existing apparatus. Power requirements and the massive handling fixtures needed are the limiting factor. An estimated cost of \$4 each was given for the 1-1/2-inch size but the set-up and die charge of \$400 to \$500 make the cost of small quantities prohibitive.

- 12 -

J. Explosive Formed

Battelle Memorial Institute^(l) is also working on various transitions, tubular and otherwise, formed by explosive charge. These are made by beveling one end of the aluminum and stainless steel tubes (at 45[°] to 60[°]) and fitting them together. A restraining plug is inserted into the tube and located at the beveled junction. A circular explosive charge is placed outside the tubes in the same location. The implosion restrained by the plug causes the metal to flow and an adherent junction is formed. This process is still in the developmental stage but junctions of good reliability have been made up to 6 inches in diameter, using aluminum, 4340 steel, stainless steel, incomel and zircalloy. Costs are approximately 1/3 those for tandem extrusions and twice those for spin-friction weldings of comparable size. This technique may also be applicable to seam welding. A current article on shock forming²⁴ describes other applications of this technique and indicates the advancement which has taken place in recent years.

K. Brazed Junctions

The preponderance of aluminum-to-stainless steel transitions being used today are joined by brazing. A number of schemes are being used successfully, the principal difference being the prebraze surface preparation applied to one or both metals being joined.

1. Solar Aircraft^(m) manufactures and stocks lap joint transitions in sizes from 3/8-inch to 6-inch diameter pipe and tube sizes. These are dip-brazed in molten flux using aluminum braze alloys and a proprietary titanium pretreatment²⁵ on the stainless steel. The manufacturer's literature states that these units have withstood twenty temperature excursions from 600° F to -320° F with no indication of leakage. Minimum acceptance standard is 10^{-8} cc/sec on a mass spectrometer leak detector. McLaughlin and Tanabe²⁶ have also tested this unit.

- 13 -

2. Bi-Braze⁽ⁿ⁾ also manufacturers dip-brazed transition couplings employing an "aluminizing process"²⁷ as a pretreatment to the steel component. They are available in 6061 to 304 alloys in sizes from 1-inch to 10-inch pipe sizes. Prices range from \$47 to \$343 depending upon quantity ordered.

Care must be exercised in selecting an aluminum dip-brazed component in order to avoid those brazing materials which contain zinc and/or phosphorous compounts. Such contaminants are not likely to be acceptable in an ultra-high vacuum system subject to bakeout. Thorough cleaning to remove traces of chloride and fluoride fluxes is also essential.

3. Gatzek²² describes 3-inch-diameter transitions being made at North American Aviation, using a tin pre-coating on 304-L stainless steel joined to 6061 aluminum by salt-bath brazing. A nickel strike is applied prior to the electrodeposited tin. Helium mass spectrometer leak tests were limited to 1×10^{-8} std cc's/sec He. A North American Aviation proposal²⁸ reports an 8-inch-diameter transition having been dip-brazed also using a tin interface.

4. Still another approach to prebraze surface preparation is given by Nord and Huschke.²⁹ This process utilizes a 0.00075-inch vacuum evaporated titanium film on the stainless steel. On top of this is deposited 0.040 inch of 4043 aluminum alloy by means of high-rate electron beam evaporation. This surface then can be welded or brazed to. This process was developed in conjunction with Temescal Metallurgical Corporation^(d) and is capable of temperature excursions from 1000° F to -423° F. The test data report is thorough and complete. These junctions have been successfully used on J-2 rocket engine control valves. Each valve has 11 such joints. The report also describes other attempts using silver interface coatings which were not successful.

- 14 -

L. Ultrasonic Bonding

Werner Schulz in the SLAC M E & F Group suggests the use of ultrasonic energy for bonding aluminum to stainless steels. By applying a copper flash onto stainless steel sheet (and sintering 3 minutes at 900° C in dry hydrogen), he has bonded 0.001-to 0.010-inch low alloy aluminum wires to stainless steel with the use of a Mullard ultrasonic pencil transducer. The power input was approximately 100 watts, the force approximately 20 psi. In bond strength tests, the wire separated before the bond failed. The possibility of bonding circular and other shapes by this method should be investigated. The process is inherently contamination free and suitable for ultra-high vacuum use.

Reference is made to a most comprehensive bibliography on Ultrasonic Welding 30 covering the years 1960 to 1966.

M. The Formed Cavity Technique

Strictly speaking, this should be classed as a semiseparable junction. The seal is made with a low melting alloy, is easily separated, and capable of unlimited reconnections. Although the seal is not bakeable, it is all-metal and useful on certain high-vacuum applications and therefore worthy of mention. The basic principle is illustrated in Fig. 2. One component to be joined is provided with an annular re-entrant cavity on the end to be joined. The mating end of the other component is machined with a tee-shaped flange which fits into the re-entrant cavity. The walls of the cavity are tapered so that if the components tend to pull away from each other, they become more tightly wedged in the solidified low melting alloy which fills the cavity. This principle was developed at NASA-Lewis Research Center³¹ for use on boltless pressure vessel tests. Since the low melting alloy expands on cooling, it is self-sealing. Seals of this type have been used on cryogenic applications up to 2000 psi. Several other possible joint configurations

- 15 -



•

Fig. 2. The formed cavity junction.

are suggested in the report. Although only aluminum is mentioned as a parent metal, the same method could be applied to aluminum-stainless steel transitions.

N. Welded Silver Sleeve

Cryogenics Associates⁽⁰⁾ manufactures a stainless steel-aluminum transition for cryogenic use similar to one which Linde Company^(p) has used on cryogenic dewards. It is simply a silver sleeve, of adequate thickness to weld to, which is snugly fitted over the butted ends of the aluminum and stainless steel tubes to be joined. The mechanical strength of the junction is developed by the close-fitting sleeve which overlaps the end of each tube for a length approximately equal to the diameter. Cryogenics Associates offered to make two of these, 8 inches in diameter $\times 1/4$ -inch wall in 304 to 6061 alloys for \$166 each. No test data was available on this process except that they have been used in cryogenics service and are said to be vacuum tight.

O. Alumicoat Process

Some preliminary work on a transition based on hot-dip coating was done here at SLAC by Dieter Walz and Luther Lucas for use on the slits and collimators in the Beam Switchyard.

Several 6-inch diameter 304 stainless steel tubes, 3 inches long, were dipcoated all over with a material called "Alumicoat" by the Arthur Tickle Engineering Company.^(Q) One end of the tube was TIG welded to a 1/8-inch thick 6061 aluminum cover plate. This weld was made with 4043 filler and was leak tight to 10^{-10} std cc⁹s/sec. The weld appearance was excellent. The other tubes were butt-welded to 6061 aluminum tubes of the same diameter with the same filler rod. Equally good weld appearance and leak tightness were achieved. No mechanical tests were performed nor further evaluation undertaken due to the lack of developmental time available. Off-the-shelf transitions were used instead.

- 16 -

The same company produces "bi-metallic castings" in which aluminum is cast onto or around shapes of higher melting alloys to form a bi-metallic junction.

P. Centrifugal Casting

Gerald Fritzke, M E & F metallurgist, suggests the possibility of dual metal centrifugal castings^(r) as a stainless-to-aluminum transition. Usually made in tubular form, centrifugal castings can be made as large as 3 feet in diameter and up to 10 feet long. They consist of two centrifically-cast concentric layers "bonded in the casting process." "They are formed by pouring the first or outer metal into a horizontal spinning mold, protecting its i.d. against oxidation and scruff accumulation, waiting until the surface has just solidified and, without interruption of spinning, pouring the second or inner metal onto the first." The manufacturer claims a metallurigical bond with some solution (and some microporosity) at the interface. These castings have been successfully made in combinations of low alloy carbon steel, 300 and 400 series stainless steels, alloy 250 (27% Cr), and cast irons. They say they can also be made to copper if it is the inner component. No mention is made in their literature regarding aluminum.

VI. SEPARABLE JUNCTIONS

A. Aluminum Foil Gasket

The majority of evaluative effort on a separable transition for use on the Storage Ring has been spent on Batzer's³² aluminum-foil-gasketed, ultra-high vacuum flange system. We have adapted it to transition service by slightly re-designing the flange to be made of aluminum. By increasing the section modulus to obtain the same flange rotation for the lower stress values of aluminum (which are allowable for bakeout temperatures of 200° C), we were able to duplicate with dissimilar metals the success he had achieved with stainless steel flanges.

- 17 -

An 8-inch o.d. by 6-inch i.d. test flange set has been baked 5 times to 220° C to test the minimum tightening torque necessary on the bolts. A 1×10^{-8} std cc/sec leak occurred on the sixth cycle. After that, the bolts were tightened to the recommended torque. No further leak was found in four additional cycles. Following this, a room temperature impact test was performed on the same flange set by dropping a 3-pound weight on the edge of the flanges. Leak detector sensitivity was always 2×10^{-10} std cc's/sec per Div. (He) or better. No leaks were precipitated by dropping the weight from heights of 1, 2, and 3 feet. At a height of 4 feet, a leak of approximately 1×10^{-9} cc/sec was detected. The fault caused in the foil gasket apparently heals itself. The helium response leveled off within 2 minutes and began receding. After 10 minutes, no helium response was detected. The same result was obtained in dropping the weight from 5 feet except the size of the leak was one order of magnitude greater and it took 25 minutes to heal. A gasket cycling test was performed next on the same flange set. Ten gasket changes were made with 220[°] C bakeout applied at each cycle. One leak occurred after cooldown on cycle #4, otherwise no leaks detectable greater than the stated 2×10^{-10} std cc's/sec sensitivity. The reason for leak at test #4 could not be explained. Following this, the same 3-pound weight drop tests were repeated from 1, 2, 3, and 4 feet with the same results, no leaks until 4 feet. The 4-foot leak also healed itself. The final test was a test to determine the maximum bakeout temperature the flange set would withstand. At the 260° C test, the flange leaked upon cooling to room temperature. After disassembly, it was found the lower edge of the seal face had yielded causing a permanent set and consequent leakage.

Subsequent to this series of tests, we modified several features of the flange in an attempt to determine its limiting parameters. The results of these tests

- 18 -

have not been satisfactory. These findings will be reported when the results are sufficiently conclusive.

B. Marmon Con-O-Seal*

The Con-O-Seal^(S) principle in stainless steel materials has been used in diameters up to 20 inches for cryogenic applications, with leakage reported³³ less than 1.5×10^{-10} std cc's/sec. This sealing technique has also been used as the gate scal in a 3-inch bakeable UHV valve reported by Ullman.³⁴ The manufacturer, Aeroquip Corporation, is marketing 6061 aluminum and 321 stainless steel mating Con-O-Seal flanges as transitions. An aluminum gasket is supplied as the seal.

A test data report evaluating the performance of this type of transition is available from Aerojet-General Corporation.³⁵

C. Curvac Seal**

Ultek Corporation^(t) have adapted their 1-1/2-inch stainless steel Curvac allmetal UHV flange as an aluminum-to-stainless steel transition.³⁶ The seal is made by flaring the end of a 1-1/2-inch diameter aluminum tube and inserting the flared end into the flange in place of the copper gasket normally used. The other end of the aluminum tube projects out of the back of the flange for subsequent welding. The other stainless flange is mated to it and has a stainless steel tube welded to it in the usual manner. This seal has withstood temperature cycles from 200° C to liquid hydrogen temperature and was developed for use at the Boeing Space Environment Laboratories. Its limitation is that it will not seal leak-tight a second time on the same flanged tube end. A new tube must be inserted if the flanges are disassembled. It has only been used on 1-1/2-inch diameter flanges.

^{*}Reg. T. M. Aeroquip Corporation

^{**}Reg. T. M. Ultek Corporation

D. Conflat Seal*

Varian Associates^(u) are presently undertaking a test program for the purpose of evaluating the Conflat* and Wheeler* type UHV flanges as aluminumstainless steel transisions. As the results of this work are divulged, they will be reported.

VII. SUMMARY AND CONCLUSIONS

Twenty-Two different schemes have been reported as possible ways of making separable and inseparable high-vacuum transitions from various aluminum alloys to stainless steel alloys. Data on utilization, testing and evaluation is provided on some but lacking from many of them. Some have very limited use and still others must be treated as purely developmental. As in any situation where a choice is available, one must select that which is best suited to the application. From the results of our present evaluation, the requirements of the SLAC storage ring vacuum system could be satisfied by the use of an aluminum foil gasketed flange for a separable connection. The roll-bonded clad metal type junction would serve well as an inseparable junction, assuming no difficulties are encountered in joining it to the vacuum chamber.

ACKNOWLEDGEMENT

The author is particularly indebted to E. L. Garwin for his many helpful suggestions and discussions regarding much of the material covered.

The assistance of T. H. Batzer is gratefully acknowledged for the suggested modifications to his aluminum foil flange design. Appreciation is also acknowledged for the contributions of E. Hoyt and N. Dean, and for much of the laboratory testing which was performed by H. Humphries. *Reg. T. M. Varian Associates

- 20 -

APPENDIX

MANUFACTURERS' NAMES AND ADDRESSES

- Metals & Controls Corp., Div. of Texas Instruments, Inc., 34 Forest Street, Attleboro, Mass.
- (b) Aluminum Company of America, Alcoa Building, Pittsburgh, Pa. (Stock is manufactured at the Alcoa, Tenn., rolling mill)
- (c) Composite Metals, Inc., Eighty-four, Pa. (Attention: John Ulam, AC/412,225-8400)
- (d) Temescal Metallurgical Corp., 2850 Seventh Street, Berkeley, Calif., 94710.
- (e) General Technologies Corp., 708 No. West St., Alexandria, Va.
- (f) Arthur D. Little Inc., Acorn Park, Cambridge, Mass.
- (g) Nuclear Metals Division, Whittaker Corp. West Concord, Mass. 01781(Attention: Wilson Tuffin.)
- (h) Tube Turns, Division Chemetron Corp., Louisville, Kentucky 40201
- (i) Electrofusion Inc., 104 Constitution Drive, Menlo Park, Calif.(Attention: Ken Olson.)
- (j) Applied Radiation Corp., Div. High Voltage Engineering Co., 2404 North Main Street, Walnut Creek, Calif.
- (k) Thompson Electric Welder Co., 161 Pleasant Street, Lynn, Mass. 01901
 (Attention: David Belforte.)
- (l) Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio 43201
- (m) Solar Aircraft Co., Subsidiary of International Harvester, San Diego, Calif.
- (n) Bi-Braze Corp., 44 Sea Cliff Avenue, Glen Cove, Long Island, N. Y. 11542
- (o) Cryogenics Associates, Inc., 3760 W. Morris Street, Indianapolis, Ind. 46241
 (Attention: Mr. Rex Leonard.)
- (p) Linde Company, Union Carbide Corp., 61 East Park Drive, Tonawanda, N.Y.

- (q) "Alumicoat" Process, Arthur Tickle Engineering Co., 21-29 Delevan Street, Brooklyn, N. Y.
- (r) Dual Metal Products, United States Pipe & Foundry Co., Steel Tubes Div., Burlington, New Jersey
- Marmon Division, Aeroquip Corp., 11214 Exposition Boulevard, Los Angeles, Calif., 90064
- (t) Ultek Corporation, Box 10920, Palo Alto, Calif., 94303
- (u) Varian Associates, 611 Hansen Way, Palo Alto, Calif., 94303(Attention: Wm. Wheeler)

REFERENCES

- "Proposal for a High Energy Electron-Positron Colliding Beam Storage Ring at the Stanford Linear Accelerator Center," Revised September 1966, Stanford University, Stanford, California.
- 2. IBID, Section C.3, p 53.
- 3. R. Addis, L. Pensak and N. Scott, "Evaluation of a New Fluoroelastomer as a Gasketing Material for High Vacuum Systems," Transactions, Seventh National Symposium, Amer. Vac. Soc., 34-44 (1960).
- 4. "Nuclear Radiation Effects on Elastomers," ASTIA, #AD 282467, North American Aviation Space and Info. Sys. Div. NAA SID 62-386.
- 5. P. W. Hait, "The Application of Polyimide to Ultra-High Vacuum Seals," Transactions, 13th National Symposium, Amer. Vac. Soc., October 1966.
- Robert A. Schultheiss, "Layered Metals," ASME Pub., 65-MD-IZ, Amer. Soc. Mech. Engr.
- John A. Vaccari, "Clad Metals," Materials & Processes Manual #237, Materials in Design Engineering, July 1966.
- 8. C. L. Wood, "A Technical Report on Duranel* ... Stainless Clad Aluminum," Prepared by the Alcoa Process Development Laboratories, Pittsburgh, Penn.
- 9. C. H. Dulin, "A Method of Bonding Aluminum Metal to Dissimilar Metal,"
 U. S. Patent #2,908,073, October 13, 1959.
- T. H. Batzer and R. F. Bunshah, "Warm-Welding of Metals in Ultrahigh Vacuum," Jour. Vac. Sci. & Tech. <u>4</u>, 19 (1967).
- H. R. Smith, <u>et al.</u>, "Electron Beam Melting A High Vacuum Technique Applied to Metallurgy," American Vacuum Society, Transactions, Fifth National Symposium (1958).
- 12. Hugh R. Smith, personal communication.

- 23 -

- 13. J. C. Merriam, "Aluminum Plating via Alkyl Gas," Iron Age, Dec. 23, 1965, p. 52.
- 14. M. D. Miller, "Joining of Aluminum to Other Metals," Welding Journal <u>32</u>, 730-740 (1953).
- M. D. Miller and E. W. Mason, "Properties of Arc-Welded Joints Between Aluminum and Stainless Steel," Welding Research Supplement, <u>35</u>, 323s -328s, July 1956.
- J. Finke and M. L. Begeman, "Seam Welding 20-gauge Aluminized Steel," Welding Journal Supplement 42, 371s - 377s, August 1963.
- 17. R. Cole, Private communication, November 18, 1966.
- C. H. Crane, D. T. Lovell and W. A. Baginski, "Research Study for Development of Techniques for Joining Dissimilar Metals," The Boeing Company Aerospace Group, Control No. DCN 1-4-50-01068-01 (IF) CPB 02-1113-64.
- 19. P. Lowenstein and W. B. Tuffin, "Metallurgical Bonding of Dissimilar Metals by Coextrusion," Nuclear Metals Div., Whittaker Corp., West Concord, Mass.
- 20. P. Gripshover, Private communication, October 4, 1966.
- 21. Friction Welding Spins its Way Onto the Production Floor, Iron Age, October 1, 1964, p 59.
- 22. Leo E. Gatzek, "Joining Aluminum to Stainless Steel for Space Vehicle Applications," Society of Automotive Engineers, Publication SAE 650754
- 23. C. E. Burley, "Metallurgical Research Div. Flash Welded Tubular Joints," Notebook #3038, Project 32-091-6, Physics and Electrical Section, May 1963, Reynolds Metals Company, Richmond, Virginia 23218.
- 24. M. C. Noland <u>et al</u>., "Shock Forming Bangs out Complex Parts--Accurately," Materials Engineering, May 1967, p. 66.

- 25. <u>Brazing of Aluminum to Stainless Steel</u>, Solar Aircraft Company Research Laboratories, RDR No. 1118, April 15, 1959.
- 26. E. McLaughlin and J. Tanabe, "Cryogenic Vacuum Test of Commercial Stainless to Aluminum Brazed Transition Pieces," University of California, Lawrence Radiation Laboratory, Berkeley, California, Engineering Note 4223-01-M4.
- 27. <u>Bi-Metallic Brazing</u>, Test Report produced by the Bi-Braze Corp., Sea Cliff Avenue, Glen Cove, Long Island, N. Y. 11542.
- "Development of Techniques for Joining & Forming of Dissimilar Materials," North American Aviation Space and Info. Sys., Report No. SID 64-626.
- D. B. Nord and E. C. Huschke, Jr., "Method of Brazing Aluminum to Stainless Steel for High-Stress Fatigue Application," Docket No. NAR-50317, North American Aviation, Inc., Rocketdyne Div., Canoga Park, Calif.
- 30. "Ultrasonic Welding," AWRE Library Bibliography No. 13, United Kingdom Atomic Energy Authority, Atomic Weapons Research Establishment.
- 31. <u>A Technique for Joining and Sealing Dissimilar Materials</u>, NASA Technology Utilization Report, No. NASA SP-5061, June 1965.
- 32. T. H. Batzer, "Flange Design Using Aluminum Foil For UHV Application," Engineering Note ENA-129, (Also listed as Report No. UCID-4548,)
 Lawrence Radiation Laboratory, Livermore, Calif.
- Summary Report of Qualification and Development Testing Part No.'s 54857 and 55800 Con-O-Seal Joints, Test Report No. 1476, Aeroquip Corp., Los Angeles, Calif. 90064.
- J. Ralph Ullman, "Commercial Seals as Seats in a Bakeable Valve," Report
 No. UCRL-6565-T, Lawrence Radiation Laboratory, Livermore, Calif.

35. F. M. Henson, "An Evaluation of Gaskets, Joints and Seals for Aerospace Applications," Aerojet Test Report No. 8800-39, Aerojet-General Corp., Box 1947, Sacramento, Calif., 95809. ١.

36. Ultek Drawing No. 956-66-00, Ultek Corp., Box 10920, Palo Alto, Calif.(Attention: R. Olmstead)