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AFML USAF ltr, 12 Jan 1972

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REVIEW OF RECENT DEVELOPMENTS

Beryllium

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May 6, 1966

AD 481839

PHYSICAL METALLURGY

A comprehensive report on the mechanical behavior of beryllium as a structural material was recently presented by Conrad and Perlmutter.(1) Although the report is too long to cover in depth in this review, some of the salient points of the paper are discussed. The authors cover the mechanical characteristics of single-crystal and polycrystalline beryllium and compare them to those of other close-packed-hexagonal materials. Possible means for improving low-temperature ductility are discussed. Texture in wrought beryllium and the hot-shortness problem are considered. The effect of surface defects on mechanical properties is also covered.

The mechanical behavior of single crystals was discussed in terms of dislocation theories. On this basis, the authors find the behavior of beryllium to be similar to other close-packed-hexagonal metals. For example, the slip behavior and strain hardening during slip are much the same. Much is known about the effect of substitutional elements but nothing about the interstitials.

Low ductility of polycrystalline beryllium is apparently due to easy cleavage and to few deformation modes. Generally, properties increase with decreasing grain size according to the Hall-Petch relationship. The authors believe that the effect of purity on ductility of polycrystalline beryllium had not been well established. In their discussion, several methods were proposed for improving the ductility of beryllium. For example, decreasing the grain size of wrought materials, increasing purity, and alloying with elements such as copper would be expected to improve ductility. Also, modifying texture by controlling the fabrication history should contribute to increased ductility.

The relationship of hot shortness in beryllium with respect to the forging problem was briefly discussed. The authors discussed in some detail the iron/aluminum reaction in beryllium and its relationship to hot shortness. They alluded to a possible connection between impurities and the forgeability of beryllium. A theory was advanced for a possible mechanism to explain the loss of grain-boundary cohesion resulting from aluminum-beryllium eutectic formation.

Splat cooling was employed by Nuclear Metals to produce fine-grain high-purity beryllium with a minimum of texturing.(2) By using this technique, fine-grain materials of SSR-grade purity were produced. Splats of beryllium, Be-0.15Fe, Be-1Ni, and Be-4Cu, were consolidated and then remachined and consolidated to eliminate layering. Cracking was pronounced in the iron alloy in the as-hot-pressed condition.

Tensile and bend tests were performed on flats that were extruded from the various alloys. In all cases, ductility was low and the strength was very high, especially for materials of these purities. Postfabrication heat treatments decreased tensile properties for all alloys and increased the elongation in the unalloyed beryllium and beryllium-nickel alloy. Grain size was stable even after annealing 1 hour at 1100 C (2000 F), which was surprising for an alloy of this purity. Highest strengths were obtained with the iron and copper alloys, but these were very brittle even after thermal treatments.

The authors suggested that the high thermal stability and strength and low ductilities were associated with one or more of the following:

(1) Unique distribution of dispersed phases because of splatting

(2) A high degree of cold work due to chip machining and low-temperature processing

(3) An atypical extrusion texture that inhibited ductility in both testing directions.

FABRICATION

Investigators at Franklin Institute have recently reported on the effect of prior history on properties of beryllium.(3) High-purity (SR grade) powder was used to produce sheet by compression rolling, upset forging of powder, and upset forging of hot-pressed block. Bend properties and preferred orientation were determined after various thermal treatments. The overall properties were compared with commercial powder-metallurgy sheet.

In compression-rolled sheets, the material having the lowest reduction appears to have the highest bend ductility. In the hot-upset sheet, bend ductility tended to increase with increased reduction. Hot-forged block showed the best bend properties in the study. This suggested to the

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authors that the upsetting caused a bending together of the particles, which would cause some basal plane disorientation.

Bend properties on commercial sheet were approximately the same as those of the compression-rolled SR beryllium. Since the reduction ratios are approximately the same, the authors indicated that there might be no effect of purity on the properties in this range. However, they noted that lack of an optimized fabrication schedule for the high-purity sheet might contribute to this occurrence.

Texturing was greatest in the compression-rolled sheets, and least in the forged material. However, no significant difference was noted in the bend ductility of the two materials. From this, the authors concluded that preferred orientation alone is not the determining factor in determining bend ductility.

MECHANICAL PROPERTIES

Brush Beryllium recently published a statistical survey of all their sheet products manufactured in 1964.(4) Table 1 gives the data as reported. In the original document, histograms of the data are plotted. The authors note that the data compare very favorably with information reported for aluminum and titanium alloys currently being used in structural applications. Table 2 gives data for hot-pressed block fabricated during the same period.(5)

ANALYSIS

The objective of a Nuclear Metals program was to develop techniques for determining carbon and nitrogen levels in high-purity beryllium.(6) Techniques developed were to be of sufficient simplicity so that interested facilities could use them without elaborate equipment. Also, standards were to be prepared that would allow the various facilities to verify the capabilities of the technique.

Modifications were made in the combustion-conductometric method so that the amount of carbon released for analysis could be increased. The best technique employed consisted of burning the sample in the presence of copper rings, which were used as coupling and fluxing agents. Using this method, carbon contents on the order of 25 ppm were determined.

Reliable analytical methods for nitrogen were developed using a modified micro-Kjeldahl still. Results were consistent even in the 10 ppm range.

Three batches of beryllium carbon and nitrogen standards were prepared. The first, from distilled beryllium, had 25 ppm carbon and 11 ppm nitrogen. The others were from SR-grade material and contained 101 and 120 ppm carbon and 55 and 56 ppm nitrogen, respectively.

CORROSION

Corrosion of beryllium in aqueous-salt environments was studied by Pronchko.(7) Rates for intermittent total-immersion testing at 15 C (59 F) were as follows: 0.8 mpy in distilled water, 13.7 mpy in synthetic seawater, 18.4 mpy in natural seawater, 21.5 mpy for 3 percent NaCl solution, and 33.4 mpy for 3.5 percent NaCl. Continuous-immersion rates in natural seawater measured on both pickled and anodized beryllium were 6.4 and 0.3 mpy respectively. The anodized treatment afforded considerable protection in this environment.

In addition to the general attack experienced in the various environments, pitting was shown to be serious in the chloride-containing environments. Pits measuring nearly 8 mils deep were noted after 30 days in 3 percent salt solution. Anodizing appeared to impede pitting, but it was not effective in eliminating it.

Limited stress-corrosion studies were also performed in natural seawater. Time to failure for pickled specimens was 190 hours at 20,000 psi and 100 hours at 30,000 psi. The anodized specimens were insensitive to the different stress levels as they both failed in approximately 360 hours. Failure was generally associated with the pitting attack. Pitting occurred continuously during the test, and the pits acted as stress concentrations that caused premature failure.

STRUCTURES

In a continuing study at McDonnell Aircraft, design criteria and manufacturing technology are being generated for using beryllium in the rudder for the Phantom II aircraft.(8) It was shown in the report that a weight savings of 46.5 percent less than that of the current production rudder was realized. This report, which covers Phase II of the project, indicates that the rudder can be fabricated using state-of-the-art procedures.

With the exception of a few clips and the aluminum honeycomb core, all the components aft of the hinge centerline will be made from beryllium sheet. Corrosion tests were conducted in a salt-spray solution to determine satisfactory coatings for service. Zinc chromate primer was satisfactory for internal surfaces. Epoxy enamel, anodization, and arc inorganically bonded aluminum coating were unsatisfactory. The enamel blistered, the anodize treatment reduced mechanical properties, and the aluminum coating spalled under loading. However, they all afforded a high degree of protection to the beryllium.

Very few problems were encountered with the conventional manufacturing operations used in producing the test elements. Details of the machining and forming operations indicated that techniques are similar to those employed for other beryllium structures. Bonding of the aluminum honeycomb core to the skin sheets was also readily accomplished. Results of all the qualification tests were given in the report.

GENERAL

Proceedings of the 1963 Gatlinburg Conference on the physical metallurgy of beryllium have been published recently.(9) This conference was sponsored by the AEC through Oak Ridge National Laboratory, with participants from the United States and the United Kingdom. Several reports in the general area of purification and its effect on

TABLE 1. STATISTICAL ANALYSIS OF BRUSH S-200 BERYLLIUM SHEET MECHANICAL PROPERTIES FOR 1964[4]

Property	Number of Tests	X	S	Brush Specification Minimum	"A" Values	"B" Values
			Longitudinal			
F_{tu}, ksi	410	80.9	2.9	70.0	73.7	76.9
F_{ty}, ksi	410	55.0	2.9	50.0	47.7	50.9
e, percent	410	19.3	5.9	5.0	4.6	11.1
			Transverse			
F_{tu}, ksi	411	80.0	2.6	70.0	73.5	76.4
F_{ty}, ksi	411	55.5	2.4	50.0	49.5	52.1
e, percent	411	17.8	5.3	5.0	4.6	10.4

TABLE 2. STATISTICAL ANALYSIS OF BRUSH S-200 BERYLLIUM BLOCK MECHANICAL PROPERTIES FOR 1964[5]

Property	Number of Tests	X	S	Brush Specification Minimum	"A" 99-95	"B" 90-95
			Longitudinal			
F_{tu}, ksi	508	47.8	2.4	40.0	42.0	44.6
F_{ty}, ksi	508	36.5	2.7	30.0	29.9	32.8
e, percent	508	1.3	0.3	1.0	0.7	1.0
			Transverse			
F_{tu}, ksi	508	51.4	2.2	40.0	45.9	48.3
F_{ty}, ksi	508	36.7	2.6	30.0	30.2	33.1
e, percent	508	2.1	0.5	1.0	0.9	1.4

properties of beryllium were presented. Also, some information is given on the properties of polycrystalline materials, especially ingot sheet. A review of structural applications in the UK is included. Much of the work in this publication has been supplemented by later conferences and publications, but it is of value to the interested reader.

REFERENCES

(1) Conrad, H., and Perlmutter, I., "Beryllium as a Technological Material", Franklin Institute, Philadelphia, Pa., and Air Force Materials Laboratory, Wright-Patterson AFB, O., Report AFML-TR-65-310, Contract AF 33(615)-2390 (November, 1965) DMIC No. 63487.

(2) Muller, W. C., Wolff, A. K., and Kaufmann, A. R., "Study of Methods to Control Grain Size, Porosity, and Texture in Beryllium and Beryllium Alloys", Report No. NMI-8001.6, Nuclear Metals Division of Textron, Inc., West Concord, Mass., Contract NOw-65-0084f (March 1, 1966) DMIC No. 63640.

(3) Hoover, D. B., Damiano, V. V., and Herman, M., "Effects of Thermo-Mechanical Variables on the Texture and Bend Ductility of High-Purity Beryllium Sheet", Franklin Institute, Report AFML-TR-65-309, Vol. I (December, 1965) DMIC No. 63671.

(4) Wyatt, H. W., "Statistical Summary of Production Beryllium Sheet Mechanical Properties for the Year 1964", Brush Beryllium Company Technical Information Sheet 112 (January 17, 1965).

(5) Private communication, Wyatt, H. W., Brush Beryllium Company (March 15, 1966).

(6) Aronin, L. R., Bauman, F. A., and Wolff, A. K., "Preparation of Standard Samples and Development of Analytical Techniques for Carbon and Nitrogen in High-Purity Beryllium", Report AFML-TR-65-195, Nuclear Metals Division of Textron, Inc., West Concord, Mass., Contract AF 33(615)-1692 (October, 1965) DMIC No. 63310.

(7) Pronchko, R. J., Myers, J. R., and Saxer, R. K., "Corrosion of Beryllium Sheet Material by Chloride-Containing Aqueous Environments", Paper presented at the 21st Annual NACE Conference, St. Louis, Missouri, March 15-19, 1965, DMIC No. 59904.

(8) Finn, J. M., "Beryllium Structure for Flight Vehicles", Phase 2 Report, McDonnell Aircraft Corporation, St. Louis, Missouri, Contract AF 33(615)-2974 (December 30, 1965) DMIC No. 63170.

(9) "Conference on the Physical Metallurgy of Beryllium", Oak Ridge National Laboratory, CONF-170, April 30 - May 1, 1963.

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