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UCID-17281

Lawrence Livermore Laboratory

A CRYOFORMING EVALUATION USING GOLD-5% COPPER

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September 20, 1976

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Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

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A CRYOFORMING EVALUATION USING GOLD-5% COPPER

ABSTRACT

In the first of this series on cryoforming, we found that high purity nickel exhibited high stability and advantageous response to cryoforming. This report deals with gold-5% copper, which exhibited serious instability even in its higher strength states. The uniaxial specimens in this investigation make such instabilities appear even worse. The major effect of higher strain rates and lower forming temperatures was to extend the homogeneous deformation range, which generally allowed higher attainable strengths.

Biaxial testing could suppress the low-strength instabilities but probably not the higher-strength instabilities. However, it was possible to produce a 110-ksi, 7%-elongation material by cryoforming at a relatively low deformation (23 to 32%). The literature indicates a minimum 50% deformation for this material is usual, which would produce a 150- to 200-ksi strength. If the instabilities can be suppressed, then room temperature (RT) working might be as effective as cryoforming. Cryogenic (or RT) spinning/forming could then produce an exceptionally strong structural material.

The history and phenomenology of cryoforming plus references may be found in UCID-17265, the first in this series of cryoforming reports. This is the second of a series.

PROCESS EVALUATION PLAN

We set out to investigate the cryogenic work behavior of materials of interest to us. Specifically we looked at the effects of forming temperature, forming rate, and post-forming heat treatment (if possible) on ultimate strength and ductility (elongation). We asked two basic questions:

- Are there significant advantages to cold forming over room-temperature forming?
- Are there significant advantages to high-rate forming over slow-rate forming?

Often the prime reason for a material choice is not strength alone. Electrical, chemical, or neutronic properties, or some other special behavior, may be first in importance. In some instances, the first consideration can be reasonably satisfied, along with strength-size

limitations, by choice of a treatable alloy. In others, the prime factors so outweigh all other considerations that a material is "the only one." The problem then is to arrive at a reasonable strength to minimize size-weight. Many of these special purpose materials are those whose only strengthening mechanism is cold work.

We chose this material on the basis of possible interest to LLL programs. The gold-5% copper has good strength, excellent electrical and thermal characteristics, and corrosion resistance, as well as a face-centered cubic (fcc) structure. It is the second of an intended series of materials to be cryoformed; the first was high-purity nickel.

At the time, the most direct approach seemed to be that of uniaxial specimens prestrained at various temperatures and rates, then tested at room temperature and conventional test machine slow rates. Alloys of this type are used mostly in jewelry and are closely related to a family of dental alloys. Some exhibit substantial age hardening because of an ordering transformation in the solid state. However, significant effects from this ordering belong to alloys having more than 8 to 10% copper.¹ In fact, all are generally cold worked.¹

The red, 18-karat (~75%) gold-copper is particularly troublesome to work because of ordering transformations in the solid state.² Phase diagrams for the gold-copper system are shown in Refs. 1 and 3.

Some gold-copper alloys exhibit large differences in resistivity between ordered and disordered lattices.⁴ This property can be useful in determining the amount of a given phase presence.

APPARATUS

The special apparatus used for high-rate forming is shown in Fig. 1. We accomplished medium and slow-rate forming and all other testing with conventional testing machines and extensometry.

A traveling-stage optical system was used to make gage length and specimen dimensional measurements.

Fig. 1. Apparatus for high-rate straining.

TYPICAL TEST PROCEDURE

1. Check dimensions and scribe gage marks on specimens.
2. Optical measurement of gage length and cross section.
3. Use high-rate machine or conventional test machine for prestraining.
4. Optically measure prestrain and new cross section.
5. Test to failure in conventional manner with extensometer strain measurement.
6. Make final optical strain measurement.

SPECIMEN CONFIGURATION AND COMPOSITION

The gold-5% copper specimens were machined from cast bars to determine uniformity. The material was made by a supplier using 99.999% gold and 99.999% copper supplied by Lawrence Livermore Laboratory (LLL). The specimen has a 12.7-mm (1/2-in.) gage length and a 4.06-mm (0.160-in.) diameter with threaded ends (see Fig. A-1 in the appendix).

The gold-5% copper was initially made in three batches. While the first and third were reasonably close in behavior, the second was so different in elongation as to cast doubt on the amount and/or distribution of the copper present. The data presented in this report are those of the first and third batches.

FORMING AND TESTING CONDITIONS

These are the pertinent strain rates and temperatures for both prestraining and testing:

Pre-strain Rates

Fast	$10^2/\text{sec}$
Medium	$10^0/\text{sec}$
Slow	$10^{-4}/\text{sec}$

Test Rate

Slow	$10^{-4}/\text{sec}$
------	----------------------

Pre-strain Temperatures ($^{\circ}\text{C}$)

Liquid Helium (LHe)	-269
Liquid Nitrogen (LN)	-196
Room Temperature	24

Test Temperature ($^{\circ}\text{C}$)

Room Temperature	24
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RESULTS

The gold-5% copper was quite a contrast to the stable behavior of the high-purity nickel (see UCID-17265). While the nickel exhibited large homogeneous deformation ranges, the gold-5% copper exhibited several instabilities -- some at very low deformations and at practically all preforming temperatures and rates.

Figure 2 shows the plot of attainable strength against preforming deformation for the first batch. All the different preforming temperatures and rates seemed to fall in a band of points up to about 13% elongation, followed by sharp rises.

The sharp rises indicated that instabilities (confirmed by optical measurements) had occurred in these uniaxial specimens. Usually called "necking," this instability does not invalidate the strength achieved but simply means that the volume of the specimen being worked is reduced to the necking region. This means that the effective gage length is reduced, and, therefore, the correct elongation is much greater than that calculated from the original gage length. Extrapolating the initial slope of the curves provides an idea of the correct elongation required to produce the given strength.

Of course, uniaxial specimens don't effectively duplicate biaxial-forming stresses. In a tensile-tensile biaxial condition, it should be possible to suppress these instabilities to some degree.

The plot of attainable strength against preforming deformation for the third batch is depicted in Fig. 3. Similar behavior to the first batch is indicated in that the instabilities generally occurred in the same elongation regions. Here instability occurred at 8% elongation at RT slow-rate forming. Again, the faster rate LN forming seemed to hold off the onset of the instability. The LHe formed material didn't seem to suffer the extent of instabilities that its counterpart in the first batch did. It also produced slightly lower strengths than the LN formed material -- the opposite of the first batch result.

Since each of these points represents an individual specimen, individual specimen differences could undoubtedly influence the instabilities.

The major effect of higher strain rates and lower forming temperatures was to extend the homogeneous deformation range. Generally, this allowed higher attainable strengths.

It was possible to produce a material having a 105- to 110-ksi strength and a 2 to 7% elongation with a 23 to 32% preforming elongation. We extrapolated the preforming elongation figure from Fig. 2, and assumed no instabilities. According to the literature,¹ these alloys are generally worked a minimum of 50%. A linear extrapolation then indicates an extremely strong material of the order of 150 to 200 ksi.

When we stress-relieved the highly worked material, it appeared to regain a few percent ductility before significant loss of strength. Our tests were too few to be conclusive, however.

Sufficient time was not available to explore aging properties of the formed material.

Fig. 2. Gold-5% copper-Batch 1 showing uniaxial instability at all forming temperatures and rates.

Fig. 3. Gold-5% copper-Batch 3 showing uniaxial instability at all forming temperatures and rates.

CONCLUSIONS AND RECOMMENDATIONS

Based on the gold-5% copper results, the following conclusions are noted:

- Gold-5% copper exhibited serious instabilities in the uniaxial tensile mode.
- At cryotemperatures strain rate effects on the strength of the material appeared to be insignificant when compared with similar deformation. However, the homogeneous deformation range was extended which generally allowed higher attainable strengths.
- Cryogenic forming temperatures did not show a large or consistent advantage over each other or over RT forming in attainable strength at comparable deformations. There was, however, a homogeneous deformation range advantage of the cryoforming over RT forming.
- Although biaxial tensile-tensile mode testing should suppress the observed instabilities, it would probably not change the other conclusions except that the attainable strength should increase significantly.
- Cryoforming can produce a high strength gold-5% copper material in the 110 ksi, 7% elongation range at a 23 to 32% deformation. A 150- to 200-ksi material is possible with a 50% deformation. Sufficient time was not available to explore aging properties of the formed material.

If sufficient interest can be generated, we would like to pursue some biaxial cryoforming and testing. This is a much better test than uniaxial specimens because of the instabilities inherent in some materials under uniaxial loading.

ACKNOWLEDGMENTS

We wish to thank R. G. Stone for his support of this project under auspices of the Engineering Research Program, and J. R. Kuhlman, who did most of the high-rate deformation and was responsible for all such fixturing. Thanks are also due to R. L. Brady and R. Cortez for their contributions to the testing program. Professor Amiya Mukherjee was very helpful during the course of the investigation.

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3. "Metallography, Structures and Phase Diagrams," Metals Handbook, Taylor Lyman, Ed. 8th Edition, Vol 8, American Society for Metals, Metals Park, Ohio (1973) p. 267.
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APPENDIX
TEST RESULTS FOR GOLD-5% COPPER

Note: Dimensioning and tolerancing are per USASI-Y14.5
positional and form tolerances apply R.F.S.
surface texture per USAS-B46.1

Fig. A-1. Tensile specimen (details found in drawing AAA72-105467-OB).

Table A-1. Gold 5% copper.

First batch	Coldworking		Testing		
			Temp. (24°C)	Rate (10 ⁻⁴)	
Sample number	Temp (°C)	Strain rate	Elongation (%)	Elongation (%)	Stress (ksi)
729	24	10 ⁻⁴	7.0	10.5	76.8
731	-196		4.4	13.8	76.4
730			12.3 ⁿ	6.9	80.5
728		10°	3.8	15.5	—
732			6.2	14.3	78.6
733			8.0	13.6	80.5
734			11.2	7.5	84.7
745			13.0 ⁿ	8.4	90.6
738			15.7 ⁿ	2.0	94.5
735			18.9 ⁿ	1.3	106.8
736	-269	10 ⁻⁴	5.2	14.4	79.5
741			7.6	13.5	81.2
737			9.0	13.2	83.6
743			9.8	10.7	85.1
742			9.9	11.7	84.0
739			10.1	10.8	83.2
744			10.8	14.2	84.5
748			11.0	13.9	86.5
746			11.8	—	—
749			12.8	11.4	85.1
740			15.4 ⁿ	2.3	105.9
747			26.0	—	—

n Necking

Table A-2. Gold 5% copper

Third batch	Coldworking			Testing		
				Temp. (24°C)	Rate (10 ⁻⁴)	
Sample number	Temp (°C)	Strain rate	Elongation (%)	Elongation (%)	Stress (ksi)	
1473	-269	10 ⁻⁴	6.7	29.3	70.5	
1474			7.0	—	—	
1475			9.0	25.0	73.4	
1472			9.8	26.8	72.1	
1477			10.6	25.7	76.3	
1476			11.8	27.2	75.4	
1479			11.8	24.6	77.9	
1478			12.5	22.6	77.3	
1482			15.6	15.3	83.6	
1480			16.1 ⁿ	10.7	88.0	
1488			16.6 ⁿ	12.2	83.4	
1481			18.7 ⁿ	14.2	86.4	
1490			19.5 ⁿ	10.6	85.6	
1489			20.2 ⁿ	10.7	88.4	
1483			20.7 ⁿ	12.5	89.4	
1465	24		8.0	7.2	86.4	
1466			8.0	6.1	88.2	
1467			8.0	8.0	81.6	
1462	-196		7.4	13.6	74.4	
1461			7.6	15.0	78.6	
1460			7.8	17.0	75.2	
1464			7.8	15.4	76.4	
1463			8.0	13.6	74.0	
1458			13.9	3.8	81.7	
1457			14.9 ⁿ	6.1	99.4	
1459			18.0	10.1	81.7	
1470		10 ²		10.2	15.6	77.9
1469				10.7	14.5	81.4
1471				11.2	14.3	79.4
1468			13.2 ⁿ	13.4	84.2	
1485			15.2 ⁿ	14.6	85.9	
1487			17.6 ⁿ	10.0	86.4	
1486			18.2 ⁿ	—	100.6	
1484			19.4 ⁿ	7.1	108.6	

n Necking

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