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LEAD-FREE AND LEADED PLUMBING ALLOYS
A COMPARISON OF HIGH TEMPERATURE PROPERTIES

Introduction

Recent mandates requiring the use of lead-free* (LF) components in potable water service have resulted in a number of new copper-based alloys being introduced into traditional plumbing applications. This NIBCO paper reports the findings from high temperature tensile strength testing of four commonly utilized copper-based plumbing alloys. These alloys include the traditional leaded alloy, C92200 steam bronze, and three others that represent leading LF alloy groups, the C89833 bismuth brass and the silicon bronze alloys: C87850 and C87600.

Background

It is important to understand the mechanical strength limits of any LF plumbing alloy throughout the installation and application temperature ranges. Plumbing components are exposed to high temperatures during soldering and brazing. Soldering typically requires minimum temperatures between 420°F and 590°F in order to melt the solder. Still more aggressive heating is required for hard soldering, silver soldering, and brazing which are done at temperatures exceeding 700°F. During such heating, internal stresses, resulting from localized expansion and contraction forces, are created within a component. These internal stresses, alone or in combination with service-induced stress, can lead to catastrophic component failures.

The 92200 bronze was chosen by NIBCO as the baseline alloy based on its corrosion-resistant material, satisfactory mechanical strength, pressure-tightness, and strength retention at elevated temperatures. The C87850, C87600 and C89833 LF alloys have been proven to be corrosion-resistant. NIBCO categorizes alloys C87850, C87600 and C92200 as bronzes, based on the contribution of silicon and tin, respectively, as performance enhancing elements. Typical mechanical properties and chemistries of the comparison alloys are provided in the following tables:

Alloy	Comparison Alloys – Chemical Composition (nominal %)					
Number	Copper	Zinc	Tin	Silicon	Bismuth	Lead
C92200	88	4.5	6	-	-	1.5
C89833	89	3	5	-	2.2	<0.09
C87850	76	20.9	-	3	-	<0.09
C87600	89	5.5	-	4.5	-	<0.09

Alloy	Comparison Alloys – Typical Mechanical Properties*		
Number	Ultimate Tensile Strength	Yield Strength (PSI)	% Elongation
C92200	34,000	16,000	22
C89833	37,000	17,000	28
C87850	63,000	26,000	25
C87600	66,000	32,000	20

* Lead Free refers to the wetted surface of pipe, fittings and fixtures in potable water systems that have a weighted average lead content ≤ 0.25% per the Safe Drinking Water Act (Sec. 1417) amended 1-4-2011 and other equivalent state regulations.

NIBCO INC.
WORLD HEADQUARTERS
1516 MIDDLEBURY ST.
ELKHART, IN 46516-4740
USA
PHONE: 574.295.3000
FAX: 574.295.3307
WEB: www.nibco.com

Testing Protocol

This study compares high-temperature mechanical properties: Ultimate tensile strength (UTS), yield strength (YS) and percent elongation, of the four alloys through 600°F. Ultimate tensile strength is a measure of the maximum stress a material can withstand while being pulled. Yield strength is the stress at which a pulled material will start to deform. Percentage elongation and yield strength combine to give a measure of the ductility of a material.

NIBCO cast samples of three of the test alloys, C92200 leaded bronze, C87600 and C87850 silicon lead-free bronzes, and an independent caster produced the third alloy, C89833 bismuth brass, for NIBCO. Subsequently, an independent laboratory, NSL Analytical, machined tensile bars and conducted the elevated temperature testing.

Test Results

The results of tensile testing are graphed in Figures 1 - 3.

The testing results revealed the following:

- Overall Strength - Values for UTS, YS and % Elongation for both the C87600 and C87850 silicon bronzes all started above both the traditional C92200 alloy and the C89833 bismuth brass. The C87850 mechanical property values were maintained at high levels throughout the test, finishing off appreciably higher at the 600˚F end point. Also, the C87600 UTS and YS values remained significantly higher than those of the leaded and bismuth copper alloys through the temperature range of testing.

- Ductility - The percent elongation of the C89833 bismuth brass was by far the lowest of the four alloys at all test temperatures. YS for the C89833 alloy drops off at 450° F, indicating a loss of ductility at that temperature. In contrast, the C92200 and C87600 alloys did not show a loss of ductility until 550° F and the C87850 alloy exhibited no such loss of ductility.

- Strength at High Temperature - The UTS of the C89833 bismuth brass was less than half of the C92200 bronze at 500°F. And at 500° F, the UTS of the C87850 and the C87600 alloys tested much higher by comparison and the C92200 and both the C87850 and C87600 bronze alloys retained good ductility at 500° F. In contrast, yield strength at 500°F for the C89833 was the same as the ultimate tensile strength for the C89833 bismuth brass, indicating the alloy became brittle.

Conclusions

The mechanical properties of C87850 and C87600 silicon bronzes held up well to high temperature exposures. These alloys are considered to be superior LF choices, especially for applications where brazing is required. When compared to the C92200 alloy, the C87850 and C87600 high-temperature mechanical properties were found to be excellent.

The C89833 bismuth brass exhibited lower overall high-temperature strength when compared to the C92200 leaded bronze and was dramatically weaker than the C87850 silicon bronze. The C89833 bismuth brass exhibited a loss of ductility at 450° F, significantly lower than the C92200 alloy. This bismuth brass is expected to have a high potential for problems associated with high temperature installation (i.e., brazing) and high pressure and temperature service.

Note: Despite this demonstration of high-temperature strength for C87850 and C87600 silicon bronzes as compared to the traditional C92200 leaded bronze, these alloys are not currently recommended for direct replacement of the current leaded bronze in high pressure-temperature service (i.e., steam). These alloys have not yet been added to the ASME Boiler Code to allow for such use.

About the Author:

Ben Lawrence, a degreed metallurgical engineer for NIBCO INC., has nearly 30 years of experience in metals manufacturing, application, and testing. He has contributed to NIBCO over the past 20 years in various positions, including corporate metallurgist and R & D manager. He is a member of American Foundry Society (AFS) and has participated in Copper Development Association (CDA) and ASTM standards development. Due to his extensive knowledge and experience, he is regularly consulted by plant and field engineers, as well as having played a role in furthering the development of "lead-free" alloys. Mr. Lawrence holds a bachelor's degree in metallurgical engineering from Western Michigan University in Kalamazoo, Michigan.

Fig. 1 - Elevated Temperature Tensile Strength

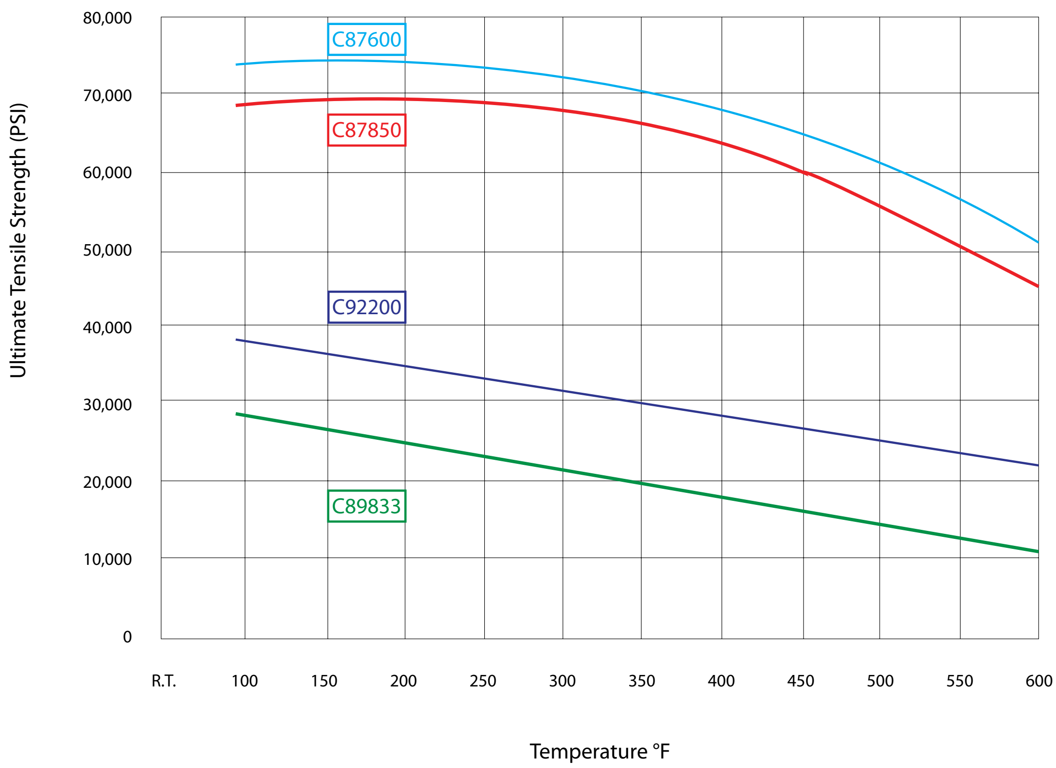

Fig. 2 - Elevated Temperature Yield Strength

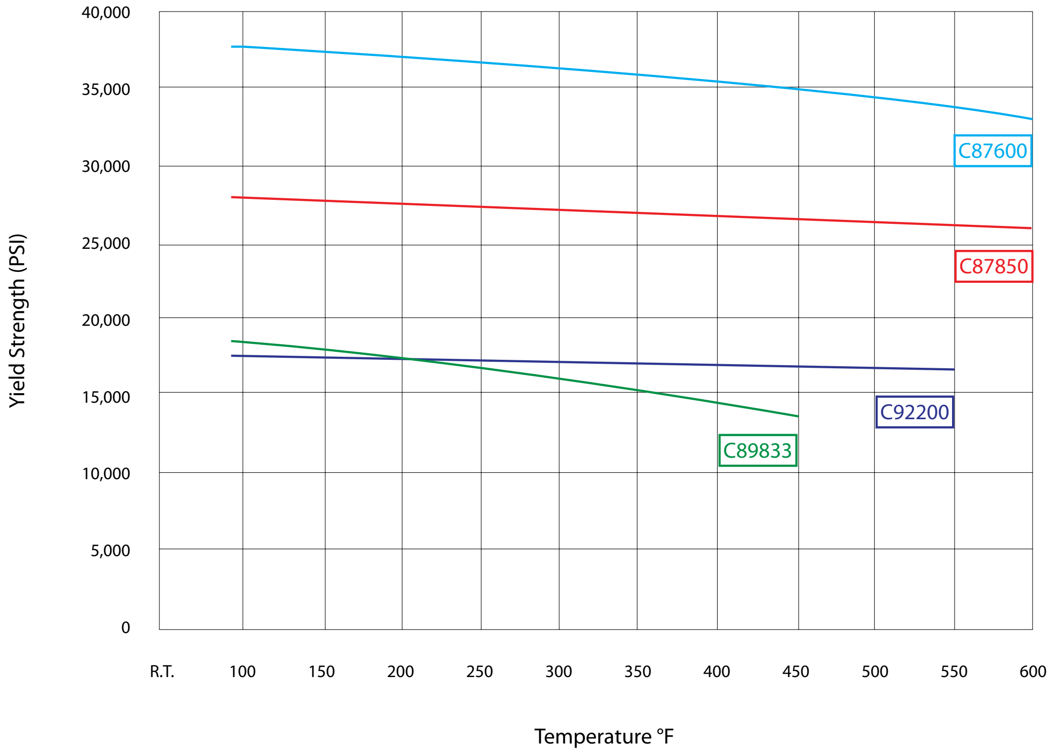

Fig. 3 - Elevated Temperature Elongation