Stretching Lead - by Arthur J. Femenella

The following discussion point is in response to a question posed to Barbara Kruger and thereby forwarded to me for an explanation.

QUESTION: Does stretching lead cames make them stronger?

RESPONSE: To give a technical answer to the question, certain properties of lead and certain scientific terms need to be discussed.

LEAD PROPERTIES Lead has a low modulus of elasticity, a low modulus of rigidity, and is a soft metal that is very malleable (easy to form). When lead is distorted (shape change due to temporary strain) it does not snap back to its original shape the way steel does. When subjected to loads, lead exhibits a high degree of creep at room temperature since its melting temperature is relatively low. No, it isn't the client that didn't pay you; creep is the plastic deformation of a metal over time. Creep can occur at low stresses, leading eventually to failure well below the nominal tensile strength of lead. If a weight is hung from a lead came, the lead came will elongate over time (this is important to remember when hanging autonomous panels). When the weight is removed, the lead will not return to its original length because it has been permanently deformed. If the weight is not removed, the lead may eventually break. Small additions of copper and/or silver to the lead form a lead alloy with much greater resistance to creep.

All materials expand or contract with an increase or decrease in temperature. The amount of this expansion or contraction is dependent on the coefficient of linear expansion a. This coefficient is very rarely linear for a material, however for most calculations a good average coefficient works well. Lead has a high coefficient of linear expansion. This means that a given length of a lead came will exhibit a relatively large elongation for each degree of temperature it gains.

TENSILE STRENGTH The yield strength of a material is the maximum amount of tensile stress (pulling apart) that can be applied to a material before it ceases to be elastic (will not return to its original shape). If too much force is applied the material will break. The property that describes the amount of stress to cause failure (seperation of the metal) is the tensile strength. The tensile strength of pure lead is much lower than that of the other common metals (mild steel is about 15 times stronger; copper 10 times stronger). As with other metals, the tensile strength of lead can be considerably improved by small additions of alloying elements. Antimony, tin and copper are commonly used.

FATIGUE This phenomenon is the failure of metals, after repeated loading cycles, at stresses below the normal tensile strength of the material. It occurs because of the growth of tiny cracks within the material - stresses at the crack tip are much higher than across the bulk of the specimen. It can be caused by mechanical loading and even cycles of thermal expansion. Lead, like many other materials, is subject to fatigue. As with creep behavior, fatigue resistance can be improved by certain alloying additions, most importantly copper.

TEMPERATURE SCALES. In the US of A, we measure temperature in Fahrenheit degrees (°F). In most of the world, and for scientific purposes, we measure temperature in Celsius degrees (°C). To convert Fahrenheit to Celsius, one subtracts 32° and multiplies the remainder by 5/9. In Fahrenheit scale the freezing point of water is 32°F and the boiling point is 212°F. In the Celsius system the freezing point is 0°C and the boiling point is 100°C.

To discuss the phenomena of what occurs when we stretch lead, we must learn about a third scale of temperature measurement, the Kelvin scale. This is a temperature scale having an absolute zero below which temperatures do not exist. Absolute zero, or 0°K, is the temperature at which molecular energy is at a minimum, and it corresponds to a temperature of minus 273.15° on the Celsius temperature scale (for the curious out there that is 492°F below zero). The Kelvin degree is the same size as the Celsius degree; hence the two reference temperatures for Celsius, the freezing point of water (0°C), and the boiling point of water (100°C), correspond to 273.15°K and 373.15°K, respectively.

During the original extrusion process a lead pig or ingot is forced at tremendous pressure through dies to form the lead cames. This pressure, in the form of shear stress, distorts (changes the shape of) the crystals of the lead from coarse to fine in structure. This adds strength to the metal and thereby rigidity to the lead cames. When a lead came is stretched on the work table prior to leading up a window, the metal once again is subject to shear strain that distorts the metal resulting in a lead came that is more rigid. However, in this instance, the added rigidity is a temporary phenomenon due to re-crystallization.

Re-crystallization or relaxation of the lead is the process whereby the metal moves from finer to coarser grains (crystals). As relaxation occurs, the lead loses all of the strength gained during stretching. Further, during deformation of the lead, dislocations are generated. During relaxation, relatively thick, disordered cell systems tend to cluster at the dislocations. This uneven grain (crystal) growth results in localized areas within the lead cames that may experience early failure. These localized sites can then form small cracks and corrosion can occur leading to fracturing and complete failure of the lead came (see FATIGUE).

Re-crystallization or relaxation of the lead occurs between 50% and 100% of the absolute melting temperature (the melting temperature of specimen measured in Kelvin degrees). For the purposes of this discussion, we will concern ourselves with pure lead cames. The melting point of lead is 327°C. This translates to 600°K, also referred to as the absolute melting temperature of lead. Room temperature is 23°C or 296°K. Therefore, room temperature is equal to 50% of the absolute melting temperature of lead and re-crystallization will begin as soon as the stretching of the lead is complete. Protective glazing studies have indicated that the temperatures the lead cames can be subject to in service can reach 140°F or 333°K. At this temperature, the rate of relaxation (re-crystallization) accelerates.

CLOSING SUMMARY Leave the extreme stretching in yoga class. The only reason, albeit a good one, to stretch lead cames is to make them straight. As soon as this is achieved the stretching process should stop. The stretching process will result in increased rigidity of the lead, but due to the phenomenon of re-crystallization this effect is temporary and will soon be lost at room temperature. A given piece of lead can only stretch a fixed amount before it will break. The continued deformation and following relaxation of the lead will form areas subject to cracking that will encourage corrosion and ultimate fracturing or failure of the lead came. The addition of small amounts of antimony, tin and copper will increase the lead alloy's resistance to deformation. Small amounts of copper or silver increase the alloy's resistance to fatigue failure.

I hope this answers the question. My thanks to Prof. David K. Matlock, Armco Foundation Fogarty Professor and Director, Advanced Steel Processing and Products Research Center for the Department of Metallurgical and Materials Engineering of the Colorado School of Mines; Frank Goodwin, VP, Materials Sciences, ILZRO; and William A. "Bud" Baeslack III, Ph.D., P.E. Dean, School of Engineering and Professor of Materials Science & Engineering at Rensselaer Polytechnic Institute for their prompt, informative responses to my inquiries and their invaluable assistance with this discussion point.

Sincerely,

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