Aleaciones de Berilio S.L. Buen Suceso 13 - 28008 Madrid - tel. 915 488 187 - fax 915 489 307 - paco_aguirre@aleacionesdeberilio.com

Technical Tidbits

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Going with the flow! This issue provides an in-depth discussion of the relationship between strain hardening and formability.

Strain Hardening and Formability

(This issue of Technical Tidbits continues the materials science refresher series on basic concepts of material properties.) The last edition of technical tidbits discussed how the strain hardening coefficient and exponent are determined from a material's true stress-strain curve. This edition continues the discussion with the practical meaning of these terms and introduces a new formability characteristic.

Recall that a material with a high **strain hardening exponent**, or **n value**, has a greater capacity for being formed (i.e., stretched or bent in a forming die) than a material with a low n value. Once strain is imparted by forming in a die or by cold rolling in the mill, the material has less capacity for additional straining. This is why materials that have been cold rolled to higher hardness have less formability than those with less cold work. Table 1 below shows the strain hardening coefficient, strain hardening exponent, and 90 degree V-block formability data for selected copper beryllium alloys. Note that the alloys and tempers with the best formability (lowest R/t ratios) have much higher strain hardening exponents than the other alloys.

For engineers designing electrical contacts and connectors, the important material properties are typically strength and conductivity. For their purposes, the 90 degree V-block formability data is usually adequate to ensure that the parts can be formed without a problem. The tooling engineer who designs the stamping die is charged with the task of converting the flat strip into the finished product. This engineer must be concerned with strength, ductility and springback as well as formability. In this case, the R/t ratio is of little use, while the n-value would help immensely in choosing the proper punches and dies. The n value is nice for determining how the material will bend and stretch, but it is not so useful in determining how material can be drawn. There are other material parameters that come into play in this case.

Poisson's ratio, commonly designated by the symbol **ν**, is the ratio of transverse (across the width) to longitudinal (down the length) *engineering* strain. Symbolically, ($\nu = e_W / e_L$). For metals, Poisson's ratio usually falls somewhere between 0.28 and 0.32. This means that for a 100% elongation, the width would contact by about 30%. Note that Poisson's ratio describes elastic behavior only.

Deep drawing is an operation that involves a substantial amount of material flow and stretching. The flat strip must flow around the base of the draw into the cup and must then be elongated as the cup is drawn out. This uses a substantial amount of strain hardening. For severe drawing operations, the material must be annealed in between draws in order to soften the material up and give it more capacity for work hardening. (In effect, the anneal is resetting the original n value.) The annealed material would then be ready for additional drawing operations.

The **anisotropy coefficient** (**r**), provides a measure of how well strip material can be drawn. Typically, this data would be available only for annealed or very lightly strengthened alloys suitable for deep drawing. As with the strain hardening exponent, this coefficient is often referred to by its symbol and is simply called the **r value**. For strip material in tension, it is the ratio of the *true* transverse strain to the *true* through-thickness stain (i.e., $r = \varepsilon_W / \varepsilon_t$). Since it is difficult to mount a strain

	Strain Hardening			R/t Formability			Strain Hardening			R/t Formability	
Alloy	K (ksi)	K (MPa)	n	Long.	Trans.	Alloy	K (ksi)	K (MPa)	n	Long.	Trans.
25 A	176	1217	0.49	0.0	0.0	3 AT	167	1148	0.13	1.0	1.0
25 1/4 H	137	942	0.17	0.0	0.0	174 HT	153	1059	0.07	1.2	5.0
25 H	170	1177	0.07	1.0	2.9	Brush 60® 3/4 HT	164	1133	0.09	0.7	0.7
190 HM	198	1364	0.06	2.0	2.0	Brush 60® HT	170	1172	0.09	1.5	1.5

Table 1 Work Hardening and Formability Behavior of Various CuBe Alloys

gauge on the edge of a piece of thin strip, the strain is usually measured in the longitudinal and transverse directions. Since the volume and the density of the material do not change in tension, the longitudinal, transverse and thickness strains must all sum up to zero. The through-thickness strain is thus equal to the inverse of the sum of the longitudinal and transverse strains ($\varepsilon_t = -\varepsilon_W - \varepsilon_L$). Therefore $r = -\varepsilon_W / (\varepsilon_W + \varepsilon_L)$.

If the material is perfectly **isotropic** (all material properties are the same in all directions), then $r = 1$. If $r > 1$, the material stretches more than it thins, and will thus flow easily into a drawing die without excessive thinning. If $r < 1$, the material will thin more than it stretches which may lead to tearing when the material is drawn. Strip materials with high r values thus are suited for deep drawing operations; whereas those with low r values can only be lightly drawn before they crack.

Astute readers may notice that longitudinal and transverse strain response within the plane of the strip are not necessarily the same, so that the r value would also depend on which direction the sample was stretched. Therefore, the reported r value is usually measured in 3 directions: longitudinal (parallel to the rolling direction), transverse (perpendicular to the rolling direction), and at 45 degrees to the rolling direction. Note that this requires 3 rectangular test specimens cut from the larger strip coil in each of the three directions. Each specimen will then have a strain gauge attached in the long direction and in the short direction, in order to measure each sample's respective r value. An average of the r values in all 3 directions is determined by calculation from the following equation: $\bar{r} = \left(r_{Long} + 2r_{45^\circ} + r_{Trans}\right)/4$

The directionality of the r value accounts for the phenomenon of **earring** when material is drawn into a cup shape. Points along rim of the cup at which the r value is higher will have more excess material left than those where the r value is lower. The size of the ears will be dependent on the following parameter, often simply called **delta r**: $\Delta r = (r_{Long} - 2r_{45^\circ} + r_{Trans})/2$

A large value of delta r implies that there will be substantial leftover material in some directions, while there will be very little leftover material, or even not enough material, in other directions. Therefore it is desirable to have a low delta r value along with a high r value.

High strain hardening exponents (n values) are important for ensuring that materials can be bent and stretched in a stamping die. High anisotropy coefficients (r values) are important for ensuring that materials can be drawn in a stamping die.

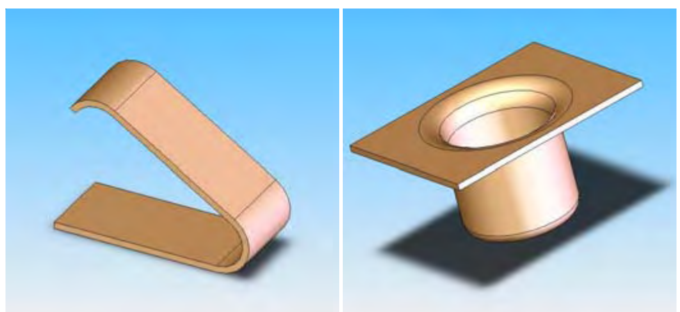

Figure 1 Bent (Left) and Drawn (Right) Features

Coming Next Issue: The next edition of Technical Tidbits will focus on fatigue strength.

Written by Mike Gedeon of the Brush Wellman Alloy Marketing Applications Engineering and Technical Service Department. Mr. Gedeon is a mechanical engineer whose primary focus has been on electronic connector markets with emphasis on Finite Element Analysis, design and material selection.

References: Hosford, William R. & Caddell, Robert M. Metal Forming: Mechanics and Metallurgy, Prentice-Hall Inc, Englewood Cliffs, 1983

Health and Safety

Handling copper beryllium in solid form poses no special health risk. Like many industrial materials, beryllium-containing materials may pose a health risk if recommended safe handling practices are not followed. Inhalation of airborne beryllium may cause a serious lung disorder in susceptible individuals. The Occupational Safety and Health Administration (OSHA) has set mandatory limits on occupational respiratory exposures. Read and follow the guidance in the Material Safety Data Sheet (MSDS) before working with this material. For additional information on safe handling practices or technical data on copper beryllium, contact Brush Wellman Inc.