Tech Brief

High Performance Alloys

Formability of Materion Performance Alloys Strip Products

Formability refers to the ability of a material to be bent to a required geometry, without cracking or failure. The formability of copper strip is dependent upon a number of variables including alloy, temper, bending direction, strip thickness, width and method of forming.

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The heat treatable tempers (Alloys 25, 360, BrushForm® 96 and BrushForm® 158) are the easiest to form during fabrication. Following fabrication, parts can be heat treated to very high strength levels. As a result, these materials provide the optimum combination of excellent formability and the highest strength attainable. In applications not requiring severe forming, mill hardened strip (Alloys 190, 290, 3, 174, 390E, Alloy 390®, Brush 60® and certain tempers of 360, BrushForm 96 and BrushForm 158) can be extremely cost effective. These materials are heat treated by Materion to deliver maximum formability at desired strength levels. Since mill-hardened strip requires no additional cleaning or heat treating after forming, manufacturing costs can be effectively reduced.

FORMING RATIO (R/T)

When strip material is formed by bending, the severity of the bend is determined by the forming ratio. This is the ratio of the inside bend radius (R) to the strip thickness (t), as shown in Figure 1. A perfectly sharp bend would have a bend radius of 0, and thus an R/t ratio of 0. Note that a lower number indicates a more severe bend than a higher number.

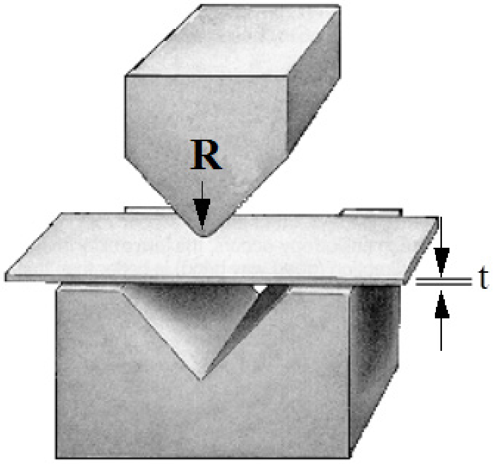
Figure 1: Various Forming Ratios

MINIMUM BEND RADIUS TO THICKNESS (MBR/T) RATIO

A material's formability rating (MBR/t) is expressed in terms of the ratio of the minimum bend radius (MBR) to the strip thickness (t). This value defines the sharpest bend (smallest R/t ratio) that can be formed without failure. Materion publishes forming limits in a 90° bend to which its strip products will form without failure. Larger MBR/t ratios indicate less formability since a larger forming radius is required. Therefore, an MBR/t value of 0 means the material can be formed around a sharp corner (zero radius) without failure. An MBR/t of 1.5 would require a bend radius of at least 1.5 times material thickness.

When selecting a strip material for your design, ensure that the material's MBR/t is less than or equal to the most severe (smallest R/t ratio) bend in the component.

Figure 2: "Vee" Block Formability Die



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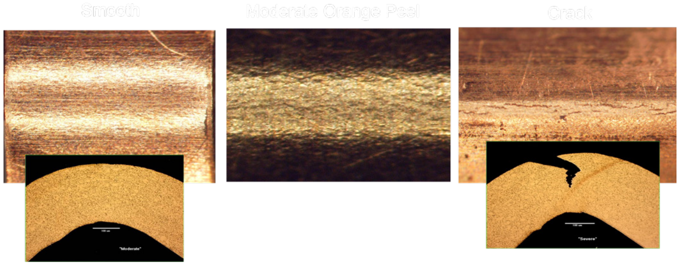
TESTING METHOD

Materion tests strip formability with a semi-guided bend test, similar to ASTM E290. The test fixture consists of a 90° "vee" block and 90° punches with various radii ground into the block with the punch (see Figure 2). Following bending, the sample is viewed at 10-30x magnification. The surface is examined for cracks on the convex side of the radius. If no cracks are visible, the sample passes the test at that radius. The punch radius is then reduced and another strip sample is formed and examined. This process is repeated until cracks appear in the sample surface. Cracks need not penetrate the sample thickness to constitute a failure. The smallest radius not to cause visible cracking is divided by the strip thickness to determine the MBR/t ratio. As in the case of a material's ductility, formability is heavily dependent upon an alloy's strength. As strength increases from cold rolling or mill hardening, formability decreases (increasing R/t ratio) and the formability becomes anisotropic (directional).

BEND SURFACE APPEARANCE

"Orange peel" is the texture on the bend surface as a result of bending and is sometimes viewed as a failure. In its milder forms, it is not cracking but only a surface change that results from deforming a straight piece of material. The presence of "orange peel" is influenced by many factors including cold reduction, grain size and direction of bending. As a result, the presence of "orange peel" is not an accurate measure of formability. Evaluation of material using this method is very subjective. Figure 3 shows a spectrum of outcomes, from a perfectly smooth bend on the left, through moderate orange peel in the center, to a crack on the right. It is up to the designer to decide if moderate orange peel is acceptable in their design. If not, better formability material may be required.

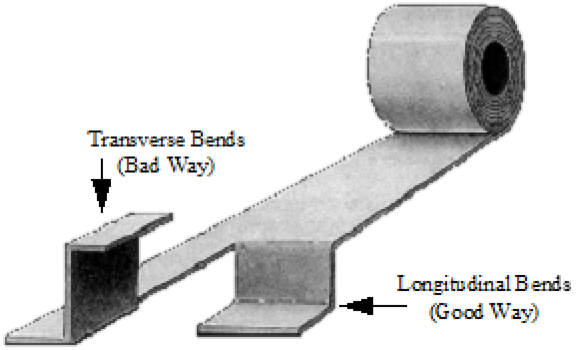
Figure 3: Different Potential Outer Bend Surface Appearances



LONGITUDINAL VS. TRANSVERSE BENDING

As shown in Figure 4, bends are termed longitudinal or transverse depending upon their orientation to the rolling direction in the strip. The anisotropy or directionality of strip properties is the result of texture effects from cold rolling. When such anisotropy occurs, the formability in the longitudinal direction (good way bend) is typically better than that in the transverse direction (bad way bend).

Figure 4: Longitudinal and Transverse Bend Orientation



EFFECTS OF STRIP THICKNESS AND WIDTH

The use of the MBR/t ratio implies that it remains invariant with thickness, but this is not the case. MBR/t ratios have traditionally been reported for strip in the 0.2 to 0.3 mm (0.008" to 0.012") thickness range. Material thinner than this will typically form better than the nominal MBR/t, particularly at foil gauges. Material thicker than test gauge may require larger bend radii to avoid failure.

Strip width also plays a role. The vee bend testing is usually done with bend coupons that typically have a greater than 10:1 width to thickness ratio, where plane strain conditions dominate. When the ratio of the strip width to thickness in a bend is less than about 8:1, the stress state shifts from plane strain to plane stress, which means the material can survive greater longitudinal strain at failure. Thus, narrower components can be formed to tighter bends than wider components. Figure 5 on the next page shows a bend coupon with three different width beams etched out of it. Note that the narrowest beam is the smoothest, and the widest beam has a crack beginning to form. All three beams are from the same test coupon, so they are all the same alloy, temper, thickness, and have been subjected to the same bend radius & R/t raito.

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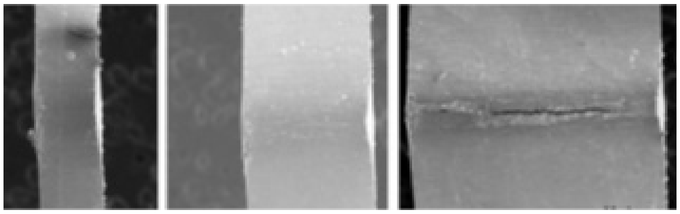
Figure 5: Effect of Strip Width on Bend Formability



DESIGN FACTORS

In determining the optimum material for a given application, there are several factors that must be considered. As temper increases, strength and hardness generally increase, while ductility and formability decrease. The highest temper that will form the part without fracture is the one that should be specified. This will effectively ensure the reliability of the design with a temper that can be readily formed.

The directional nature of formability (good way vs. bad way bends) can provide additional design flexibility, as well as efficient material use.

APPLICATIONS

Materion formability information is intended to be used as a guide for selecting the appropriate temper for an application. If the inside angle of a bend is obtuse, a radius smaller than the recommended value can be used. If the angle is acute, a larger radius may be required. The quality of the bend can also be influenced by the forming method used. For example, forming the bend in several steps, instead of just one, or rolling the material around the radius, will produce tighter bends than the R/t ratios would indicate.

OTHER METHODS TO IMPROVE FORMABILITY

If the design requires higher strength material than is allowed by the formability requirements of the design, there are other methods that can be used to locally improve the formability.

One such method is profile machining of the strip, as shown in the top of Figure 6. If the most severe bends are in the transverse orientation, then it would be possible to remove some of the material thickness on the inside the bend area by skiving or milling in a reel to reel process. This has the dual effect of reducing the strip thickness and increaseing the bend radius, which makes the bend much less severe, as shown in the bottom of Figure 6.

Figure 6: Profiled Machining of Strip to Locally Improve Formability

The second method, also for transverse direction bends, would be to use an electron beam to locally heat and soften the material within the bend area. This is typically done in a reel to reel process, and locally improves the formability while leaving the remainder of the strip in its original, high strength condition.

Figure 7 shows the effect of the zone annealing process combined with profiled machining. The black diamonds are hardness test indentations. Note that the indentations are larger in the zone annealed section on the right, indicating lower hardness and effective softening. Materion can provide both of these processes at its Lincoln, Rhode Island, facility.

Figure 7: Zone Annealing Combined with Profiled Machining

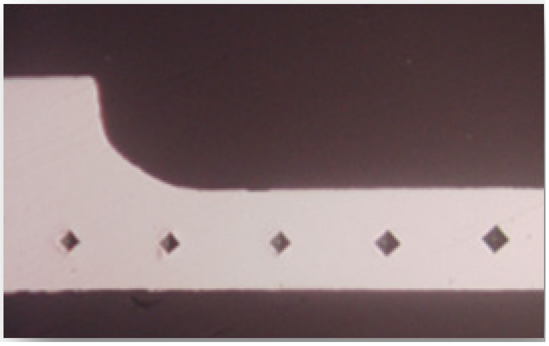


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Table 1: Guide to Strip Alloy Formability

Formability Rating	Specific Formability	Alloy and Heat-Treatable Temper	MBR/t Ratio for 90° Bend Direction of Bend		Alloy and Mill Hardened Temper	MBR/t Ratio for 90° Bend Direction of Bend	
			L	T		L	T
Excellent	Used for deep drawn and severely cupped or formed parts	25 A	0	0			
		BrushForm® 96 Alloy A	0	0			
		BrushForm 158 Alloy A	0	0			
		360 A	0	0			
	As formable as the annealed temper but easier to blank	25 1/4 H	0	0	290 TM02	0	0
		BrushForm 158 Alloy 1/4 H	0	0	BrushForm 158 Alloy TM00	0	0
		360 1/4 H	0	0	BrushForm 158 Alloy TM02	0	0
					360 MH2	0	0
Very Good	Used for moderately drawn or cupped parts	BrushForm 158 Alloy 1/2 H	0	0.5	190 AM	0	0
		25 1/2 H	0.5	1	QMet® 200 Alloy HT	0	0
		360 1/2 H	0.7	1.2	QMet 300 Alloy HT	0.2	0.2
		BrushForm 96 Alloy 1/4 H	1.1	1.7	BrushForm 96 Alloy TM00	0.2	0.2
					174 1/2 HT	0.5	0.5
					190 1/4 HM	0.5	0.5
					BrushForm 96 Alloy TM02	0.5	0.5
					290 TM03	0.5	0.5
					360 HM4	0.5	0.5
					Brush 60® Alloy 3/4 HT	0.7	0.7
					290 TM04	0.7	0.7
					190 1/2 HM	0.5	1
					3 AT	1	1
					Alloy 390E® EHT ≤0.002" (0.05mm)	1	1
Good	Formable to a 90° bend around a radius less than 3 times the stock thickness	360 H	1.2	2	BrushForm 96 Alloy TM04	1	1
		BrushForm 96 Alloy 1/2 H	1.5	2	360 MH6	1	1.2
		BrushForm 96 Alloy H	1.5	2.5	BrushForm 158 Alloy TM04	1	1.5
		BrushForm 158 Alloy H	0.5	3	Brush 60 Alloy HT	1.5	1.5
		25H	1	3	290 TM06	1.5	1.5
					360 MH8	1.2	1.6
					Alloy 390® HT ≤0.004" (0.1 mm)	2	2
					3 HT	2	2
					190 HM	2	2
					BrushForm Alloy 158 TM06	2	2
					360 HM10	1.5	2.2
					Alloy 390E EHT ≤0.004" (0.1 mm)	2	2.5
					360 MH12	2	3
					BrushForm 96 Alloy TM06	2.5	3
Moderate	Suitable for light drawing; used for springs				290 TM08	3.5	3
					190 SHM	2.8	3.2
					Alloy 390E EHT ≤0.006" (0.15 mm)	2.5	3.5
					Alloy 390E EHT ≤0.010" (0.25 mm)	3.5	4
					174 HT	1.2	5
					Alloy 390 HT >0.004" (0.1 mm)	3.5	5
					Alloy 390E EHT >0.010" (0.25 mm)	4	5
					190 XHM	4	5
Limited	For essentially flat parts; forming requires very generous punch radius	BrushForm 96 Alloy TD08	3	6	BrushForm 96 Alloy TM08	5	7
					BrushForm 158 Alloy TM08	5	8
					190 XHMS	5	10
Extremely Limited	For flat parts only; attempt to form at your own risk			1.3	EtchMet™ Alloy TM10 and TM20 Tempers	x	x
					BrushForm 158 Alloy TM 16, TM18 and TM19 Tempers	x	x

continued

NOTES ON TABLE 1:

Unless otherwise specified, and except for foil products, the formability numbers were based on 90-degree V-bend testing of strip with thicknesses ranging from 0.2 to 0.3 mm (0.008" - 0.012"). Strip less than 0.2 mm (0.008 inches) thick may form somewhat better than shown.

These numbers are provided as a guide only, and are not to be taken as a specification. If you have specific formability requirements, please let your sales engineer know at the time of purchase.

MBR = minimum punch radius that will not cause bending failure.

t = stock thickness.

FORMABILITY RATINGS OF MATERION STRIP MATERIALS

Materion's published formability values in Table 1 are for strip at 0.010 inch (0.25 mm) thick. Strip less than 0.010 inch (0.25 mm) thick will be somewhat more formable than shown. These numbers are published as a guide only and are not a specification. If your design requires that the material pass a particular R/t ratio, please specify when ordering the material.

SAFE HANDLING OF COPPER BERYLLIUM

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 Safety Data Sheet (SDS) before working with this material. For additional information on safe handling practices or technical data on copper beryllium, contact Materion's Technical Service Department at +1-800-375-4205.

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