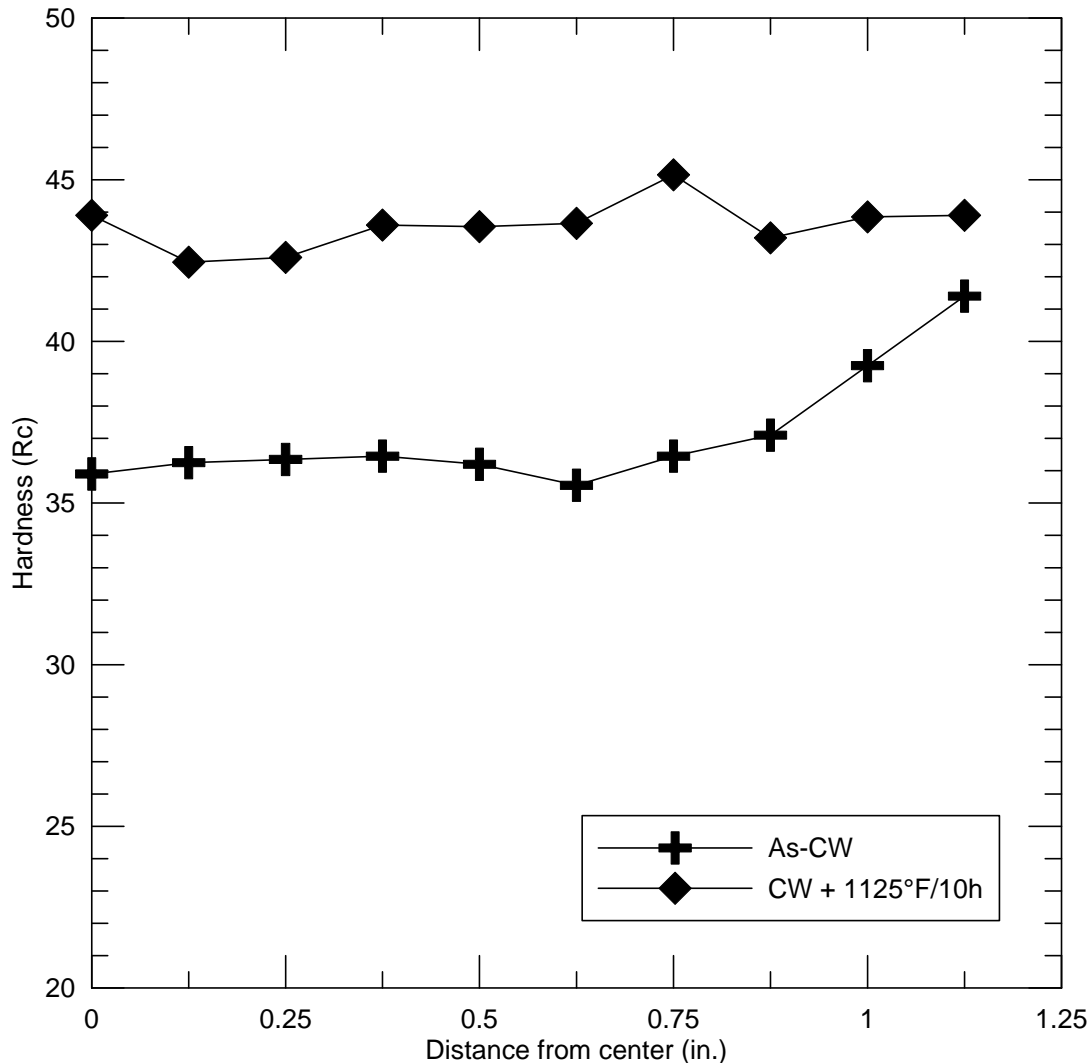


HASTELLOY® C-22HS® alloy

Anisotropic Study of Cold-Reduced Bar Product

A sample of 3.5" bar from heat 2321-2-2500 was cold pilgered to 2-3/8" bar with a 54% cold reduction. A hardness profile was taken from the center to the outside in the as cold-worked condition, as well as, in the cold-worked and age-hardened condition (CW + 1125°F for ten hours). The profile is shown below. The hardness of the as cold-worked sample shows surface hardening as expected in this operation. Note that the cold-worked and age-hardened sample has quite uniform hardness through the bar.

RC Hardness Profile on 2-3/8" C-22HS® alloy bar



HASTELLOY® C-22HS® Alloy

Tensile test samples were cut in the longitudinal and transverse directions in both the as cold-worked and the cold-worked and aged-hardened condition. The room temperature tensile results are below. The yield strength difference is about 13% lower in the transverse versus the longitudinal direction in both products. The ultimate tensile strength is lowered by 4% for as cold-worked and 6% for the cold-worked and age-hardened condition, and the % elongation values drop by 2% for both material conditions. The reduction of area is still quite high in both cases and is lowered by 14% for as cold-worked product and 12% for the cold-worked and aged product.

Room Temperature Tensile Results					
Material Condition	Orientation	Yield Strength (ksi)	UTS (ksi)	Elongation (%)	R.A (%)
As Cold-Worked	Longitudinal	181.4	190.5	21.2	71.1
	Transverse	156.6	183.0	18.8	60.9
Cold-Worked + Age-Hardened	Longitudinal	193.5	210.6	27.5	66.5
	Transverse	168.3	197.8	25.5	58.5

Tensile testing was conducted at 350°F and 450°F in both the longitudinal and transverse directions and is shown below. The longitudinal yield strength properties for the as cold-worked product from room temperature to 450°F are lowered by 14%. The transverse yield strength in the as cold-worked products is lowered by 11%. Both longitudinal and transverse yield strength in the cold-worked and aged products also are lowered by 11%.

Room and Elevated Temperature Tensile Results						
Material Condition	Test Temperature °F	Orientation	Yield Strength (ksi)	UTS (ksi)	Elongation (%)	R.A (%)
As Cold-Worked	RT	Longitudinal	181.4	190.5	21.2	71.1
		Transverse	156.6	183.0	18.8	60.9
	350	Longitudinal	160.2	166.6	18.5	72.2
		Transverse	138.3	160.9	16.1	59.6
	450	Longitudinal	156.1	163.1	18.3	72.2
		Transverse	139.0	156.7	14.8	59.3
Cold-Worked + Age-Hardened	RT	Longitudinal	193.5	210.6	27.5	66.5
		Transverse	168.3	197.8	25.5	58.5
	350	Longitudinal	179.8	179.8	25.1	66.6
		Transverse	152.1	177.1	25.8	58.3
	450	Longitudinal	173.1	173.1	25.2	62.0
		Transverse	149.7	174.8	25.4	58.1

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Charpy impact testing was conducted in the three possible orientations (longitudinal and traverse with two notch orientations) at room temperature, -75°F and -320°F. The data is below.

Charpy Impact Testing			
Test Temperature °F	Sample Orientation	Impact Energy * (ft-lbf)	
		Cold-Worked	Cold-Worked + Age-Hardened
RT	Longitudinal	148	108
	Transverse (Notch: Longitudinal)	60	56
	Transverse (Notch: Transverse)	54	49
-75°F	Longitudinal	141	106
	Transverse (Notch: Longitudinal)	63	54
	Transverse (Notch: Transverse)	52	49
-320°F	Longitudinal	99	42
	Transverse (Notch: Longitudinal)	46	41
	Transverse (Notch: Transverse)	41	34

The Charpy impact results in the transverse direction are less than half the values of the longitudinal direction at room temperature and -75°F, but are still quite high for service versus other high-strength materials. In liquid nitrogen (-320°F), the as cold-worked properties follow the trend above; however, the cold-worked and aged results are lower in all three orientations, but are still in the 34-42 ft-lbf range, which is quite high for high-strength materials in such a severe environment.