COMPARISON OF PROPERTIES AND MICROSTRUCTURES OF TRÉFIMÉTAUX AND HYCON 3HP™ AFTER NEUTON IRRADIATION - D.J. Edwards (Pacific Northwest National Laboratory)*, B.N. Singh, P. Toft and M. Eldrup (Risø National Laboratory)

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EXTENDED ABSTRACT

The precipitation strengthened CuNiBe alloys are among three candidate copper alloys being evaluated for application in the first wall, divertor, and limiter components of ITER. Generally, CuNiBe alloys have higher strength but poorer conductivity compared to CuCrZr and Cu-Al_2O_3 alloys. Brush-Wellman Inc. has manufactured an improved version of their Hycon CuNiBe alloy that has higher conductivity while maintaining a reasonable level strength [1,2]. It is of interest, therefore, to investigate the effect of irradiation on the physical and mechanical properties of this alloy.

In the present work we have investigated the physical and mechanical properties of the Hycon 3HP™ alloy both before and after neutron irradiation and have compared its microstructure and properties with the European CuNiBe candidate alloy manufactured by Tréfimétaux. Tensile specimens of both alloys were irradiated in the DR-3 reactor at Risø to displacement dose levels up to 0.3 dpa at 100, 250 and 350°C. Both alloys were tensile tested in the unirradiated and irradiated conditions at 100, 250 and 350°C. Both pre- and post-irradiation microstructures of the alloys were investigated in detail using transmission electron microscopy. Fracture surfaces were examined under a scanning electron microscope. Electrical resistivity measurements were made on tensile specimens before and after irradiation; all measurements were made at 23°C.

In the unirradiated condition the Tréfimétaux alloy possesses a higher density of smaller precipitates, producing a lower yield strength and much lower electrical conductivity than in the case of the Hycon alloy. Both alloys proved to be susceptible to embrittlement when the test temperature exceeded 250°C, exhibiting a transition from a ductile transgranular failure mode to a combination of ductile/brittle intergranular failure.

Irradiation clearly alters the microstructure and solute distribution within both alloys. Changes in the electrical conductivity (Table 1) and the size distributions of the precipitates (Fig. 1), evolution of the precipitate reflections in the diffraction patterns, as well as precipitation within the prior denuded zones, indicate that dissolution and reprecipitation occur at all irradiation temperatures to some extent depending on the irradiation conditions. The effect of irradiation is also seen in the mechanical properties (Table 2, Figure 2). Irradiation increases the susceptibility to embrittlement when tested above 250°C, while the large increases in strength that occur when irradiated and tested at 100°C suggest that radiation-induced redistribution of the solute is occurring, possibly forming small nanoscale precipitates that have not yet been observed. Various researchers [3-8] and the evidence provided in this report suggest that more than one mechanism may be responsible for the embrittlement that occurs at temperatures > 200°C, mechanisms such as solute segregation to the grain boundaries and oxygen adsorption. The effect of oxygen and possibly other

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is needs to be investigated more thoroughly through controlled experiments that the effects of temperature and strength as well as irradiation.

the Tréfimétaux alloy may simply require different thermomechanical processing to e its overall behavior, at present the Hycon alloy appears to be the best alloy for lower rature applications, especially considering its higher electrical conductivity and higher th. Careful evaluation of this material to determine the fracture toughness and crack gation characteristics at lower irradiation temperatures over a range of doses would useful.

At this point it seems unlikely that CuNiBe alloys can be recommended for applications in neutron environments where the irradiation temperature exceeds 200°C. Applications at temperatures below 200°C might be plausible, but only after careful experiments have determined the dose dependence of the mechanical properties and the effect of sudden temperature excursions on the material to establish the limits on the use of the alloy.

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Table 1. Electrical Conductivity of Unirradiated CuNiBe Alloys and Irradiated to 0.1 and 0.3 dpa at Various Temperatures.

Alloy	Irradiation Temperature (°C)	Relative Conductivity (%)
Tréfimétaux CuNiBe	Unirradiated	42.6
	100	41.4
	250	43
	350	50.1
Hycon 3HP™	Unirradiated	64.6
	100	54.9
	250, 0.1 dpa	59.9
	250, 0.3 dpa	53.9
	350	65.7

Table 2. Tensile Results on Unirradiated CuNiBe Alloys and Irradiated to 0.1 and 0.3 dpa at Various Temperatures.

Alloy	**Irradiation Temperature (°C)**	$\sigma_{0.2}$ **(MPa)**	σ_{max} **(MPa)**	ε_u **(%)**	ε_{total} **(%)**
Tréfimétaux CuNiBe	Unirradiated 22°C	585	826	23.8	28.3
	Unirradiated 100°C	590	824	21.4	28.8
	Unirradiated 250°C	630	825	15.0	19.0
	Unirradiated 350°C	Not specimens tested			
	100	885	940	3.3	5.9
	250	690	705	0.3	1.5
	350	Specimen broke in mount			
Hycon 3HP™	Unirradiated 22°C	720	800	7.2	10.2
	Unirradiated 100°C	720	780	7.2	11.4
	Unirradiated 250°C	690	730	3.0	5.1
	Unirradiated 350°C	640	680	0.9	2.7
	100	810	840	0.8	4.5
	250, 0.1 dpa	670	705	1.0	3.4
	250, 0.3 dpa	620	660	1.0	3.1
	350	405	Broke prematurely		

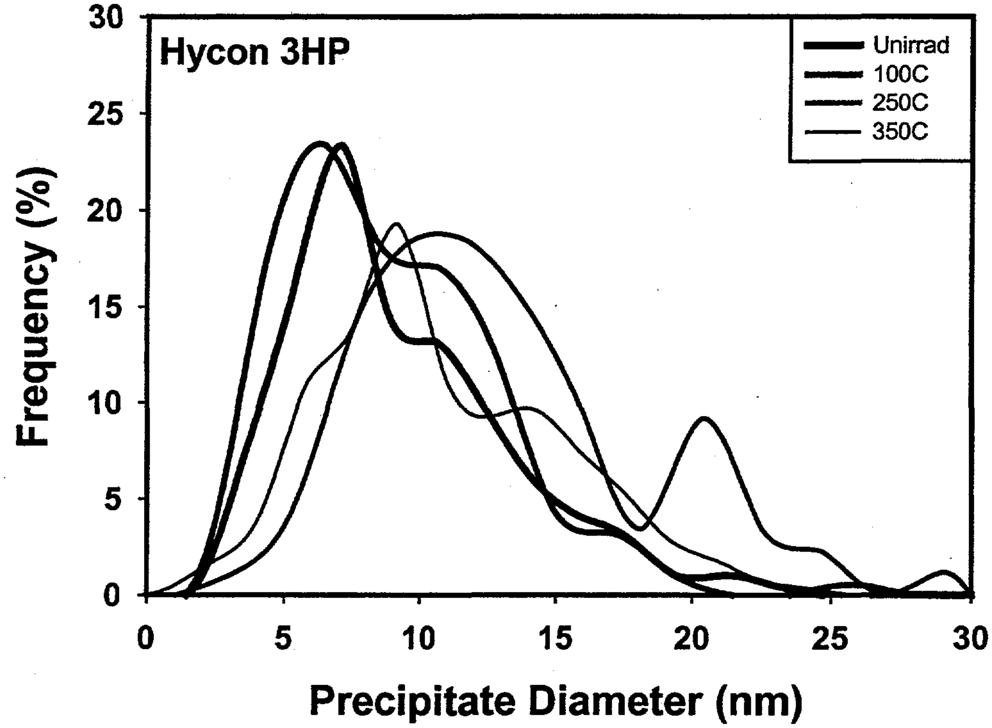

Figure 1. Size distribution of the γ'' precipitates in the unirradiated and irradiated Hycon alloy after irradiation to 0.3 dpa. Note that the size distribution broadens as the irradiation temperature is increased.

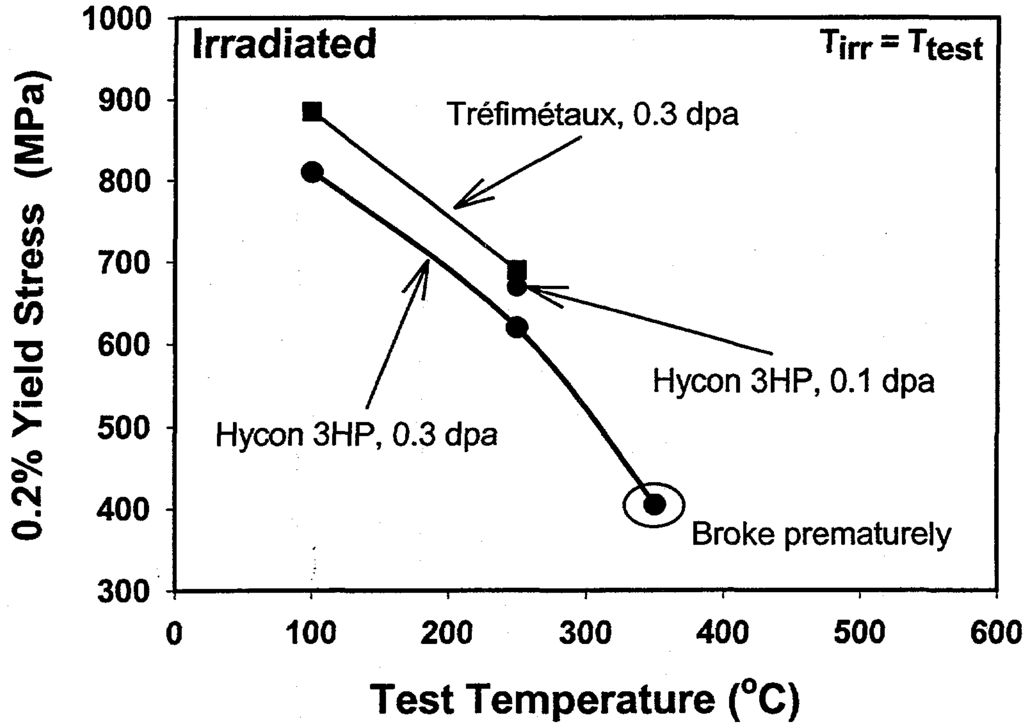

Figure 2. Yield strength of the irradiated CuNiBe alloys as a function of test temperature. Note that at $T_{test} \geq 350°C$ both alloys failed prematurely or during specimen mounting for testing, evidence of the extreme embrittlement caused by irradiation.