

**Zr0.4Nb0.8SnFeCrMn**

**Effects of Thermo-Mechanical Process on the Mechanical Properties of Zr0.4Nb0.8SnFeCrMn Alloy for Advanced Fuel Cladding Material**

150

Zr0.4Nb0.8SnFeCrMn  
 가 , 가 ( ) 가  
 , {0001} , {10 $\bar{1}$   
 0}  
 , {10 $\bar{1}$ 0}  
 가 , 가 (400  
 °C, 150 MPa) , 가 가

**Abstract**

The mechanical properties of Zr0.4Nb0.8SnFeCrMn alloy, which is under development as one of the candidate alloys for advanced fuel cladding material, were evaluated at various final thermo-mechanical treatments including cold-working and annealing temperature. The microstructure and pole distribution were observed using optical microscopy and X-ray, respectively. Tensile and creep tests were carried out at ambient temperature and 400 °C, respectively. As a result of texture analysis, basal pole was directed to normal direction, while prism pole was to rolling direction. The significant reduction of ductility was observed in stress-relieved specimen of transverse direction than that of rolling direction, but the difference was disappeared as the degree of recrystallization increased. The anisotropic behavior along to the direction of applied stress was seems to be highly associated with prism pole distribution. Further discussion was given to the effect of thermo-mechanical treatments in terms of strain hardening rate, and characteristics of toughness. Creep test result showed that recrystallization decreased the thermal creep strength at the test regime of 400 °C and 150 MPa.

1.

가 가 ,  
 가 .  
 Zry - 4  
 Zirlo[1]  
 Zr .  
 [2,3].  
 가 . Zr0.4Nb0.8SnFeCrMn  
 가 .  
 가 가  
 가 가  
 가 HCP  
 가 (texture)  
 가 X-ray  
 가 (RD)  
 (TD)

2.

1 1  
 590 °C

1.

	Sn	Nb	Fe + Cr + Mn	Zr
wt.%	0.8	0.4	0.7	bal.

25 mm, 6.25 mm ASTM 8.3 ×  
 $10^{-4} \text{ s}^{-1}$  . 25  
 mm, 5.0 mm 400 °C 150 MPa 가 240  
 가 60 %  
 15mm × 15mm  
 5° 70° Co-K X-  
 {0002}, {11  $\bar{2}$ 0}, {10  $\bar{1}$ 1}, {10  $\bar{1}$ 2}, {10  $\bar{1}$ 3} 5

harmonic method [4]  $l_{max} = 22$  ODF  
 (orientation distribution function)  
 Kearns [5] Kearns,  $f_{ND}, f_{TD}, f_{RD}$   
 RD, TD, ND

### 3.

#### (1)

2 . 2 30  
 . 470 °C 가 가 (SR :  
 stress-relieved) 490 °C , 520 °C (PRX :  
 partially recrystallized) , 600 °C (FR : fully recrystallized)  
 . 470 °C  
 가 SR .  
 가 . 3 45%  
 75% 가 (CW : cold-worked) {0002} {10  $\bar{1}2$  }  
 {0002} 가 ND TD 30  
 . {10  $\bar{1}2$  } 가 , ND  
 RD 30 . -Zr {10  $\bar{1}0$  } (prism plane)  
 . {10  $\bar{1}2$  } {10  $\bar{1}0$  }  
 , 가 47 (10  $\bar{1}0$ ) RD  
 가 -Zr  
 . Kearns  
 가 가  $f_{RD}$  .  $f_{TD}$  가  $f_{ND}$   
 RD (basal plane) ND  
 4 60% 가 ODF . ODF  
 , ND, TD, RD <0001>, <11  $\bar{2}0$ >, <10  $\bar{1}0$ >  
 , Euler . ODF Euler ,  
 , 가 0, 25, 0 5, 25, 55 가 peak , 35, 10, 25  
 peak . peak (01  $\bar{1}4$ )<10  $\bar{1}0$ > (10  $\bar{1}4$ )<01  $\bar{1}0$ >  
 Peak (0001)<01  $\bar{1}0$ > . 가, RD  
 {10  $\bar{1}0$  } , ND {0001} TD  
 가 가 .

#### (2)

6 9  
 . 가  
 , (ductility) . RD TD 가

가 가 (strain hardening rate :  $= d / d$  ) 가  
520 °C

가 RD TD  
TD 490 °C  
가 TD (520 600 °C) RD  
가 가 가 가  
, 600 °C 가  
가 (yield  
drop) 가 가

(3)  
10 400 °C, 150 MPa 240 가 (SR)  
440 490 °C

#### 4.

(1) 가 ,  
가 -Zr (state  
of structure)  
11 13 6 9 가 가 2가  
가 가 가 가 ,,  
가 가 가 (dynamic recovery)  
가 가  
G/200 (G ) [6].  
1,000 2,000 kgf/mm<sup>2</sup> , G , 35  
GPa [7] 10  
extensometer , cross head ,  
10  
11 가 , 가 가

가 가 가가 가  
 , 12 , 가 가  
 . Zr (strain ageing) cell  
 가 가 [8,9]. 가  
 locking unlocking  
 unlocking  
 III가 가 unlocking 가 가  
 . 가 가 III가  
 . III  
 13 TD 가 RD , III 가  
 TD II , III 가  
 .  
 . -Zr {10 10} < 11 20 > ( )  
 , c- [0001] (twinning)  
 c- {10 12} {11 21} ,  
 , {11 22} [10],  
 (CRSS) 가 . CRSS가  
 가 {10 10} < 11 20 > , 가 가  
 [11].  
 가 ( 가 가 ) {0001} ND ,  
 {10 10} RD . RD ,  
 [11 20] c- ,  
 . TD 가  
 14 [10 10] [0001] ,  
 CRSS가 {11 22} . RD  
 TD {11 22}  
 III . 9  
 , RD, TD  
 가 RD {10  
 10} TD [12, 13] . Zry -4  
 SR RD {10 10} TD ± 30  
 [13]. RD, TD  
 가 가 .

(2) (toughness)

가

(toughness)

(work)

15, 16 RD TD

가 CW

가

45% CW

60, 75 % CW

(600 °C)

470 520 °C

CW

440 °C

SR

, CW 가

SR

RD

SR

. TD

가

가

RD

가

{10  $\bar{1}0$ }

TD

CW - SR

, RD

{10  $\bar{1}0$ }

, TD

{10  $\bar{1}0$ }

TD

(3)

가

[8]. ,

SR

가

Limbäck

[14]

80 160 MPa

330 400 °C

385 °C

120 MPa

( 가 = 104 MPa) 가

, RX, PRX, SR

가

가 RX

Limbäck

[14]

가

가

### 5.

Zr0.4Nb0.8SnFeCrMn

가

가

(

)

가

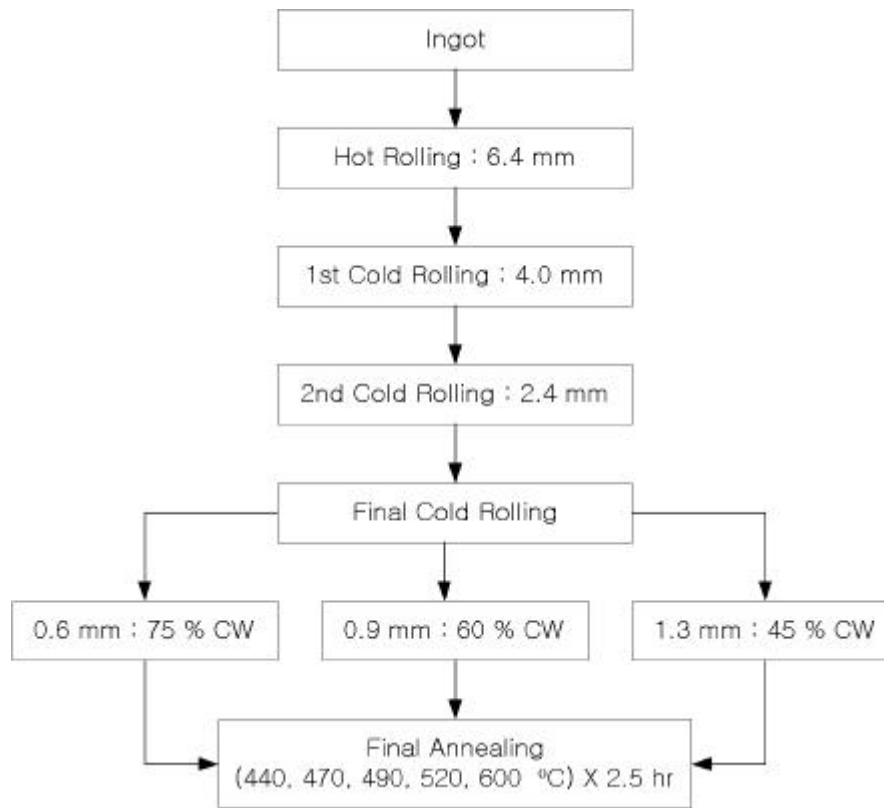
● OM , 490 °C SR, 520 °C PRX, 600 °C FR  
 . SR {0001} ND TD ± 30°  
 {10  $\bar{1}0$ } RD  
 가 가 Kearns  $f_{ND}$ 가 가  $f_{RD}$ 가  
 ODF (01  $\bar{1}4$ ) <10  $\bar{1}0$ >  
 ● , CW 가 가 ,  
 가 . ii iii  
 가 가  
 ● TD , SR RD ,  
 가 iii ,  
 SR {10  $\bar{1}0$ } RD  
 , RD  
 TD  
 , {10  $\bar{1}0$ } TD  
 ● RD (toughness) 45% CW 가  
 60, 75 % CW PRX 가 가 FR  
 . TD SR 가  
 가 TD SR RD  
 {10  $\bar{1}0$ }  
 ● 400 °C, 150 MPa , SR  
 가 가

1999

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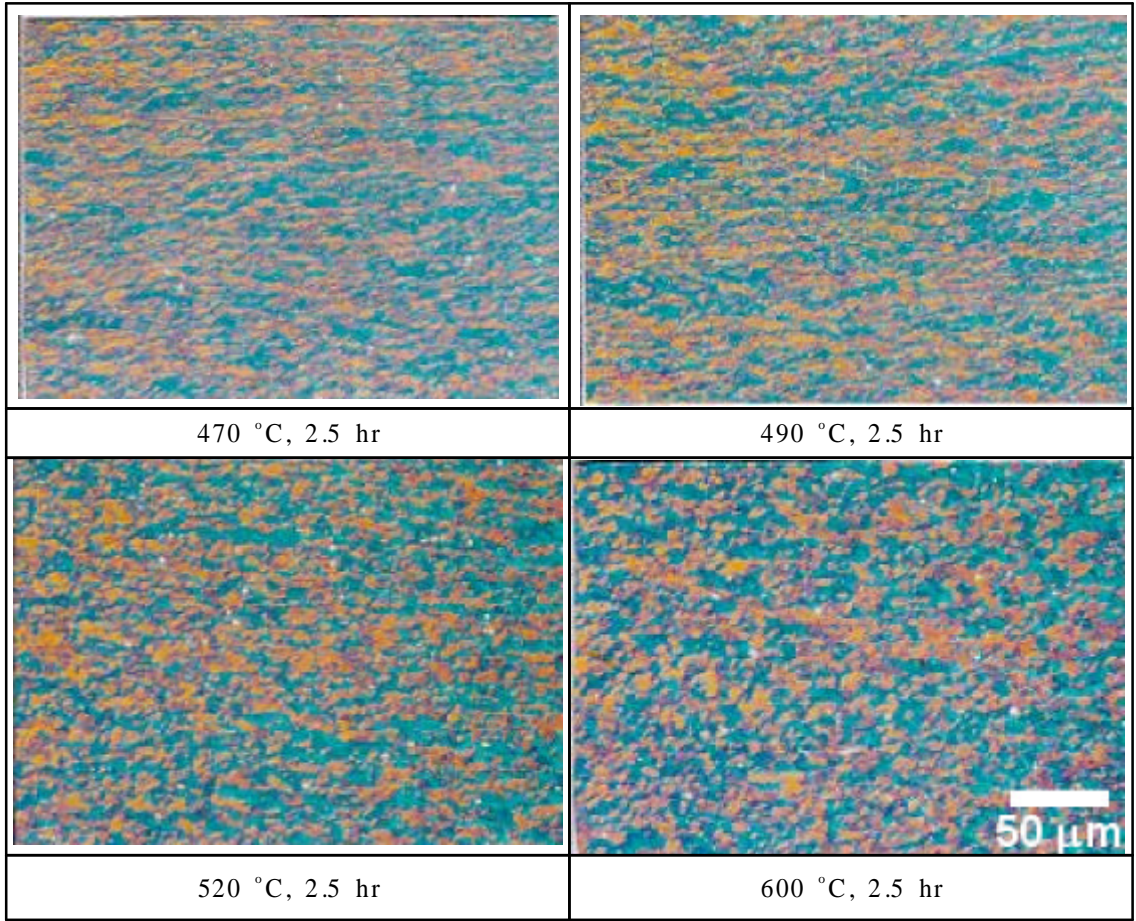
7. D. O. Northwood, et al., *J. of Nuclear Materials*, 55 (1975) 299.
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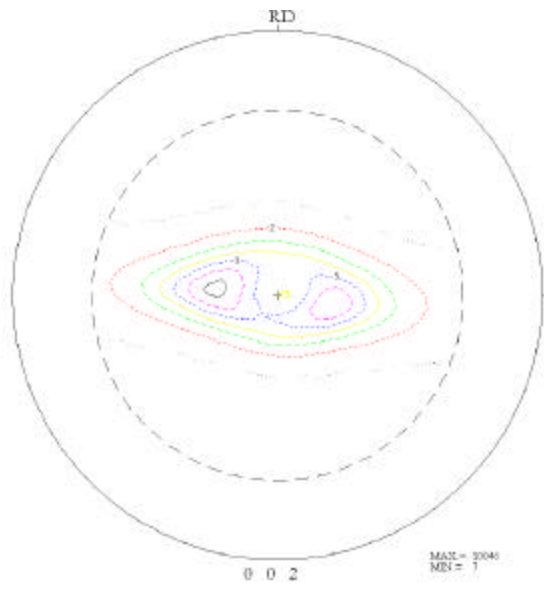
1.

Zr<sub>0.4</sub>Nb<sub>0.8</sub>SnFeCrMn  
가



2.

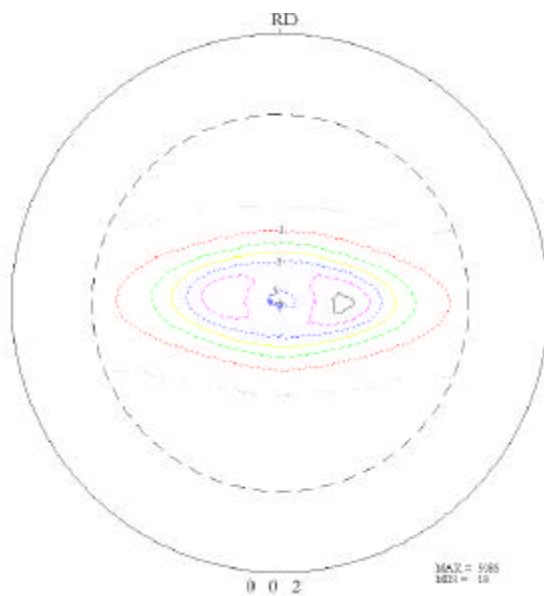
(200 )



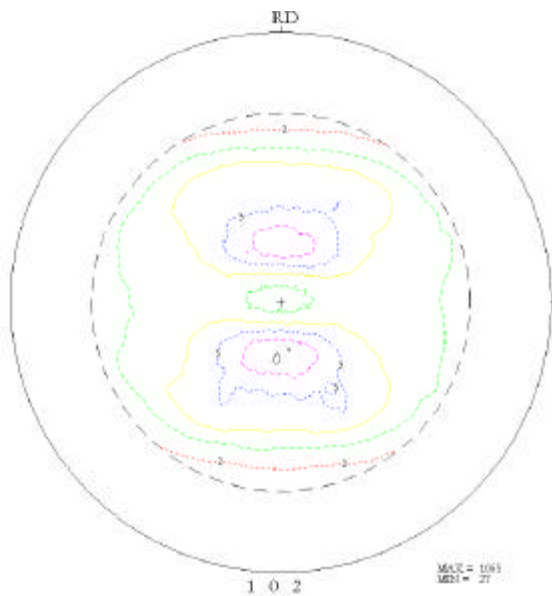
(a) 45% CW, {0002} plane



(b) 45% CW, {10 $\bar{1}2$ } plane

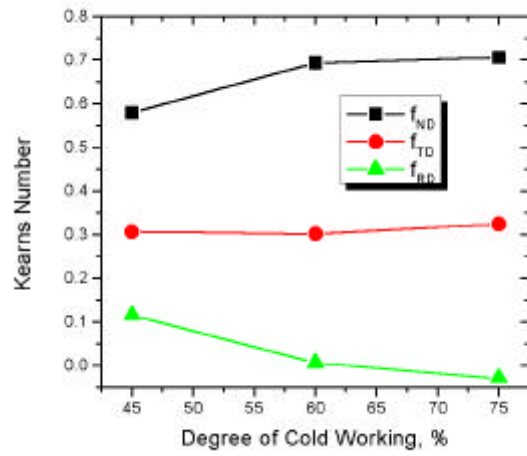


(c) 75% CW, {0002} plane

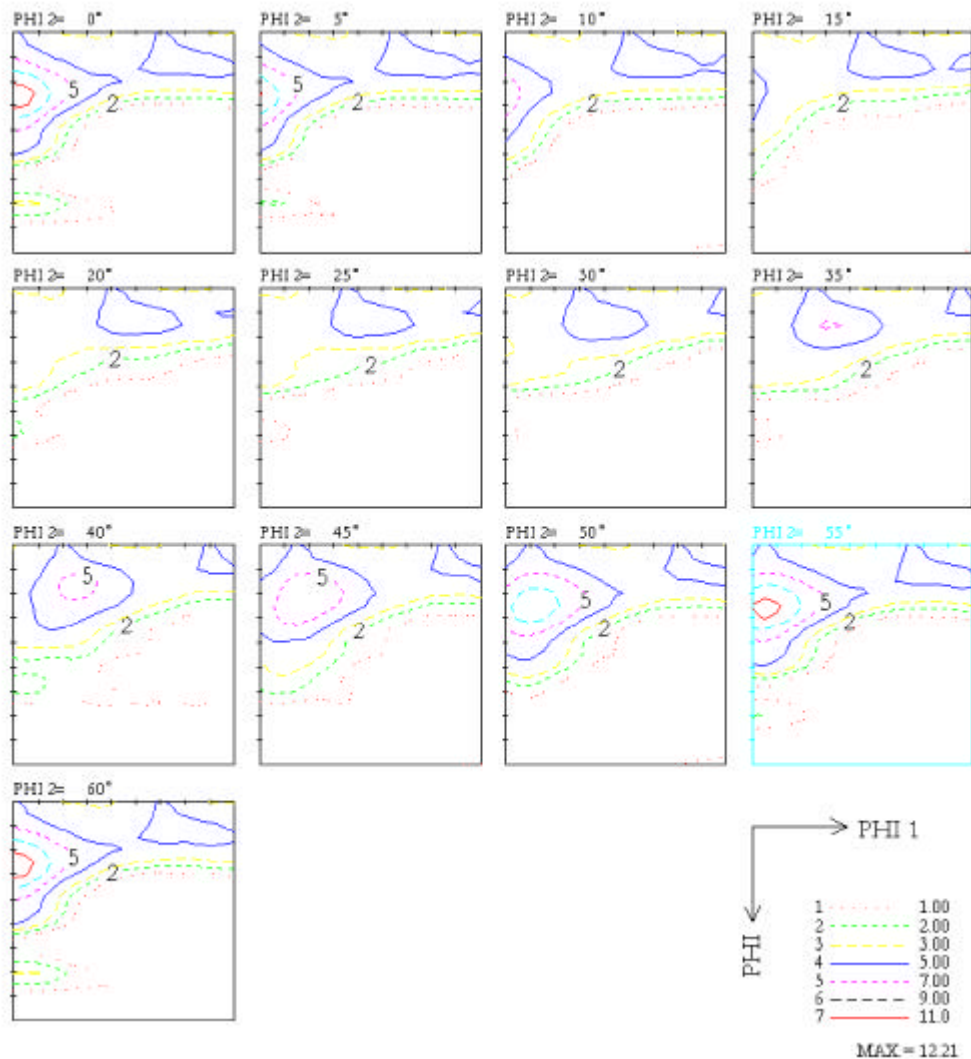


(d) 75% CW, {10 $\bar{1}2$ } plane

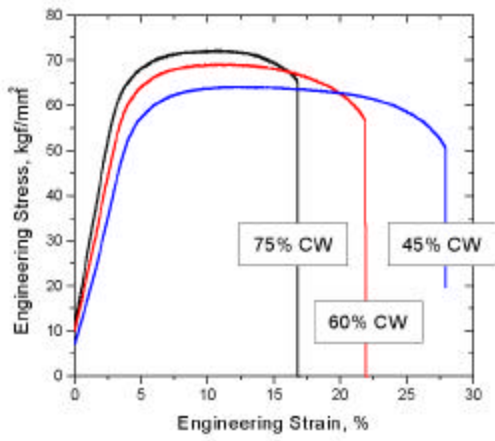
3. 가 {0002} {10 $\bar{1}2$ }



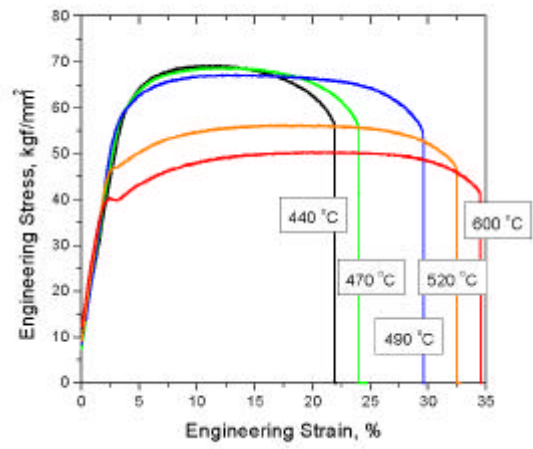
4. Kearns



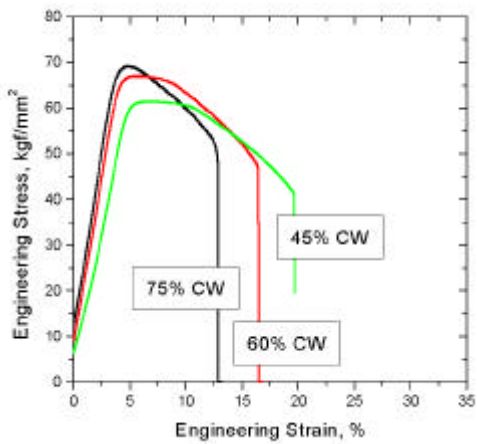
5. 60% 가 ODF



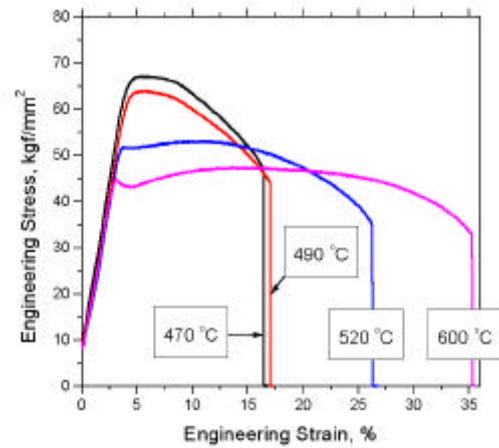
6. (RD) : 440 °C



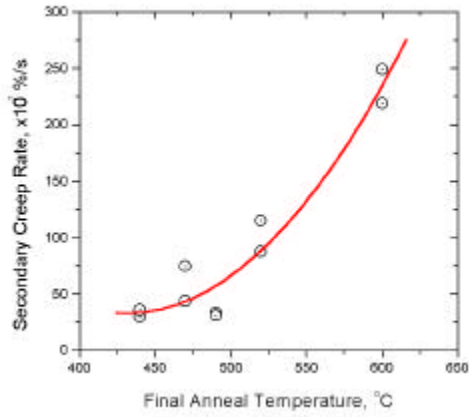
7. (RD) : 60%



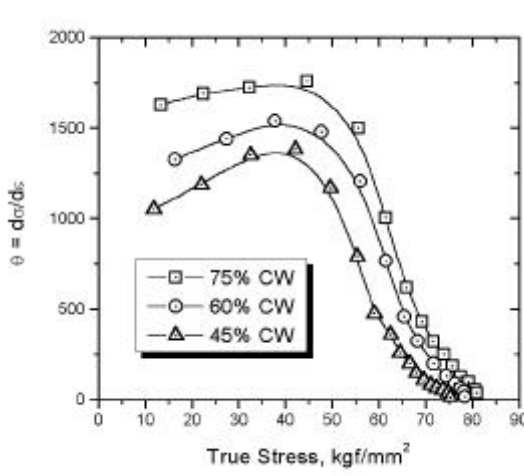
8. (TD) : 470 °C



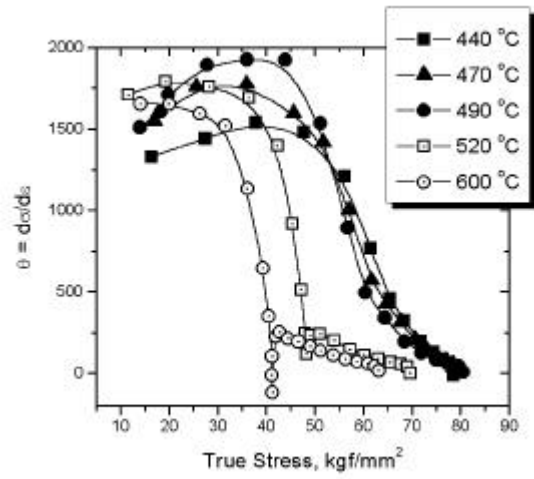
9. (TD) : 60%



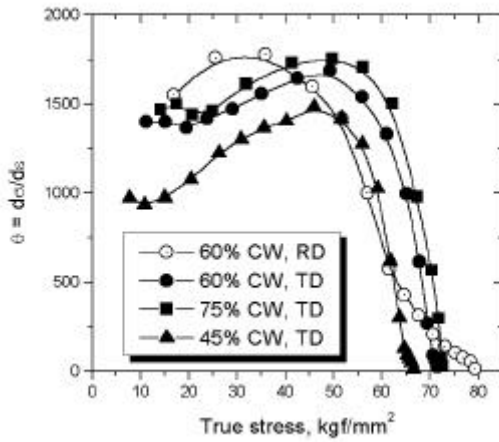
10. 150 MPa, 400 °C ( : 60%)



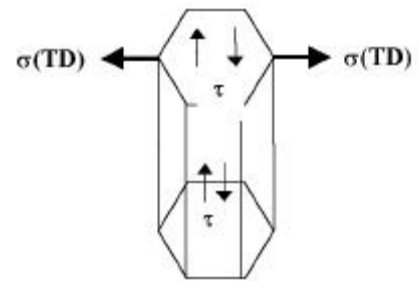
11. 가 ( : 470 °C)



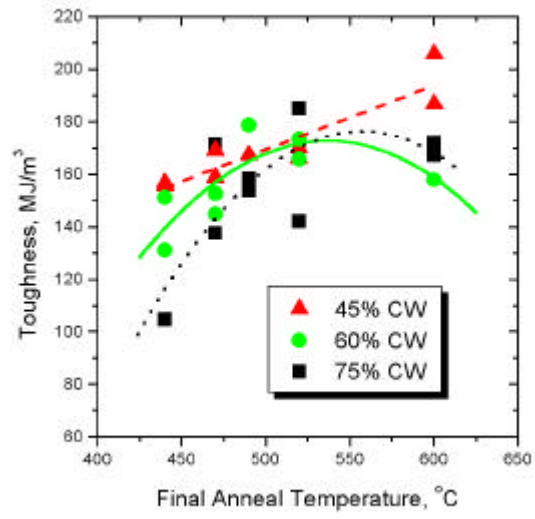
12. 가 ( : 60%)



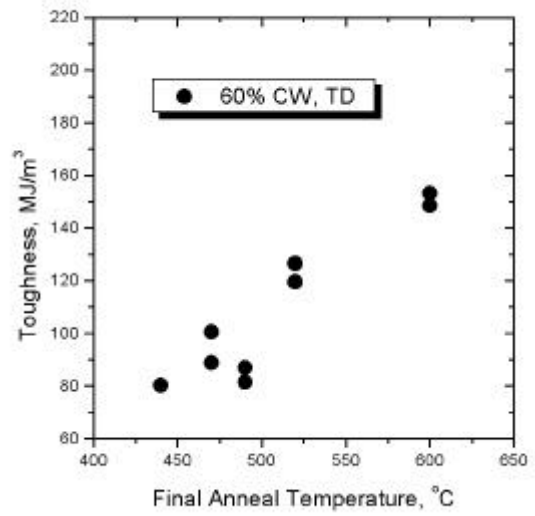
13. 가 ( : 470 °C)



14. (CW - SR) (TD)



15. 가 (RD)



16. (TD)