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Tensile Behavior of Cryorolled Zircaloy-2

By P.Aditya Rama Kamalanath & Apu Sarkar
N.I.T.Warangal, Warangal, India

Abstract - Zircaloy-2 is mainly used in nuclear technology, as cladding of fuel rods in nuclear reactors, especially water reactors (BWRs). Hence high strength of Zircaloy-2 is of prime importance. This investigation deals with the effect of cryorolling on Zircaloy-2 by comparing different tensile properties. For this analysis, four samples with various degrees of cryorolling are taken and tensile tests are conducted on these samples. The obtained results are analyzed and the optimum degree of cryorolling of Zircaloy-2 is obtained. The cryorolling improved the mechanical properties of the material as the dislocations are entangled near the grain boundaries and also due to decrease in the grain size. The microstructure of the sample is analyzed by optical microscope, before and after cryorolling and the grain structure analysis is done.

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I. Introduction

Zirconium has very low absorption cross-section of thermal neutrons, high hardness, ductility and corrosion resistance. Hence its alloys are mainly used in nuclear reactors for the cladding of fuel rods. Zircloy-2 is one such alloy which is mainly used in boiling water reactors(BWR). In the recent past, water reactors of higher capacity are being developed .In the late 1990s GE Hitachi(GEH) and Toshiba has produced advansed boiling water reactor(ABWR). The standard ABWR plant design has a net output of about 1350 MWe (3926 MWth). Various tests are being conducted on zircaloy-2 at such high burn-up[1], and while the zircaloy-2 cladding has had a very good track record of safe use in nuclear reactors, the material becomes susceptible to failure over long times for the above ABWRs at such high burn-up. As a result, fuel rods are often taken out of service even though they may have a substantial amount of fuel remaining to produce energy[2]. So methods which increase the strength of zircaloy-2 without decreasing its ductility and corrosion resistance are being explored.

Cryorolling, deformation at cryogenic temperature is proved to be effective method for increasing the yield strength and tensile strength for various Al alloys[3],[4]. So this technique is implemented on zircaloy-2. Also optimum degree of cryorolling for zircaloy-2 is also found in this investigation.

Author α : Department of metallurgical and materials engineering, NIT Warangal, Warangal, 506004, India.
Author σ : Mechanical metallurgy section, BARC, Mumbai, 400094, India.

II. Experimental Procedure

Process of cryorolling: The samples are dipped in LN2(liquid nitrogen) for 10min before first pass and 2 min for each pass, sample was found to attain nearly -160^{0}C. The process is controlled by microprocessors in order to avoid thermal shocks and also damage to the components.

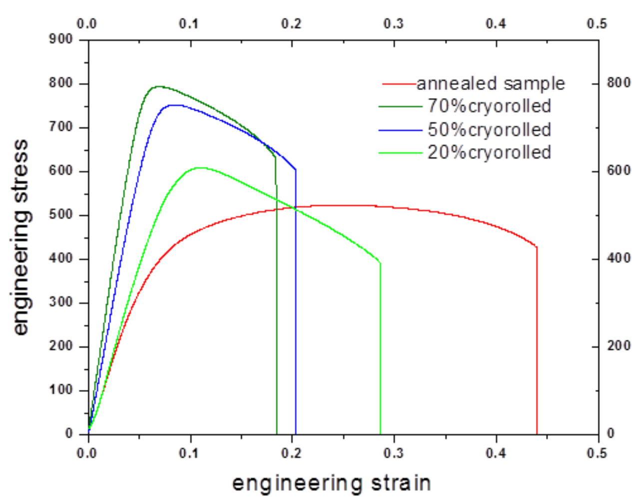
Here in cryorolling as the material cools its molecular structure contracts and hence there is entanglement of dislocations near the grain boundaries.

The samples are cryorolled up to three degrees of rolling (leaving the annealed sample) .One up to 20%; another to 50%: and the last one up to 70% of cryorolling.

Then the material is tested by tensile testing machine and the testing data is supervised by blue-hill software to get the required data of the material.

Then graphs are simulated using the data obtained for both annealed sample and cryorolled sample using ORIGIN PRO software.

III. Results and Discussion

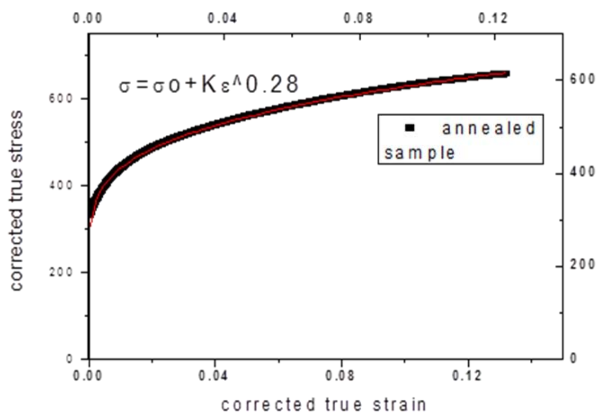


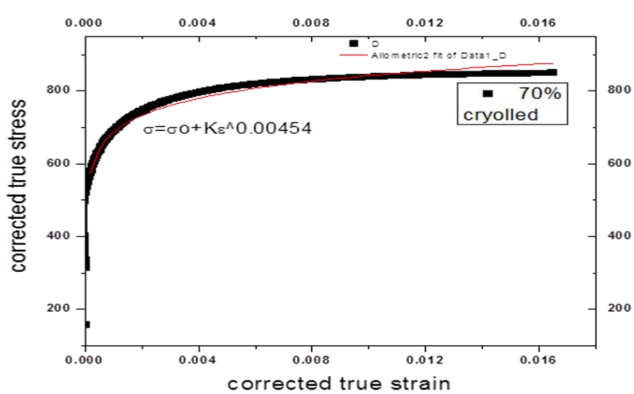
This shows that the Yield stress and the Ultimate tensile stress of the sample increases with the % of cryorolling.

a) The values obtained from the graph are

	Annealed sample	20% cryorolled sample	50% cryorolled sample	70% cryorolled sample
Yield stress	381 MPa	496.5 MPa	668.9 MPa	732.3 MPa
Ultimate Tensile stress	523.26 MPa	609.5 MPa	753.5 MPa	795.9 MPa
e_u	0.23	0.106	0.083	0.07

b) Strain Hardening curve

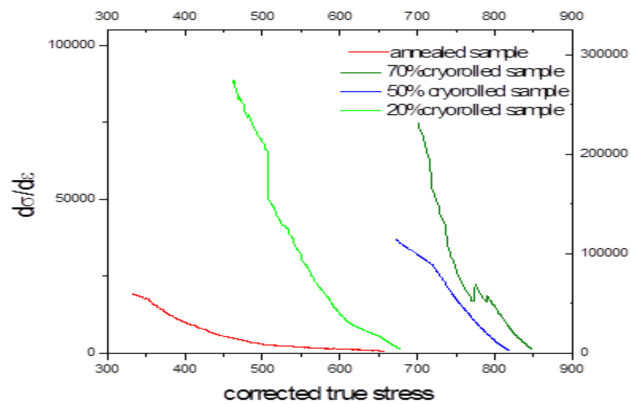




It is found that the value of n is found to decrease from the annealed sample to 70% cryorolled sample indicating that the mean free path of the dislocations has decreased with cryorolling due to their increasing density.

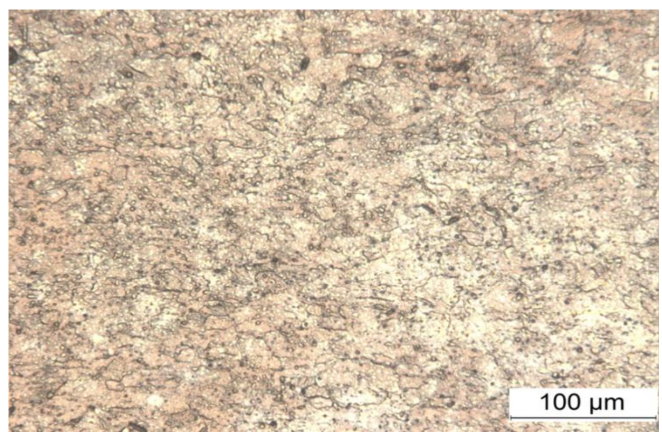
	Annealed Sample	20% cryorolled	50% cryorolled	70% cryorolled
n	0.28	0.04	0.019	0.004

c) Work hardening

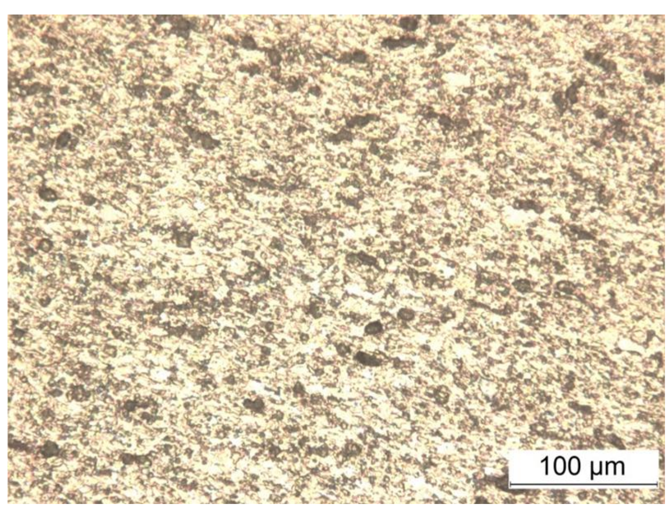


These curves show that there is a decrease in the dynamic recovery pace with the % of cryorolling.

d) Microstructure Analysis



Optical microscope Image of Annealed sample



Optical microscope Image of 70% cryorolled sample

There is a noteworthy decrease in the grain size from annealed sample to 70% cryorolled sample.

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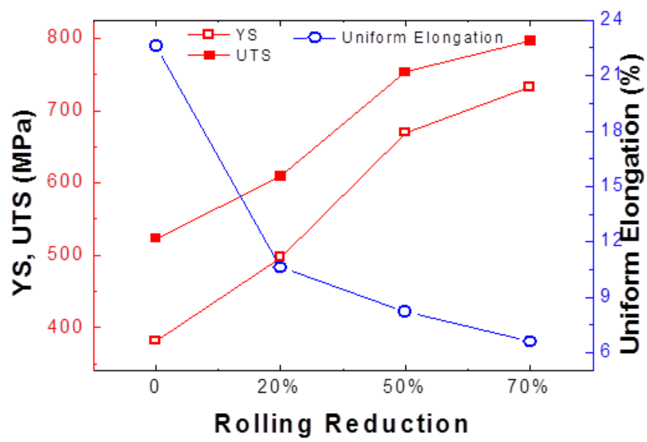
IV. Conclusions



We observe that with the increasing amount of cryorolling there is a significant increase in the Y.S and U.T.S at the cost of its ductility. An optimum degree of cryorolling is obtained between 20%-50% of cryorolling.

Due to cryorolling, we get

a. Fine grain size and
b. More dislocation density
c. Suppression of dynamic recovery.

i. *Fine grain size*

Normally for annealed sample the dislocations are present within the grain and the grain boundaries. When some stress is applied, the dislocations move along one grain to another. In this process, when it comes through another grain, it encounters a barrier due to the misorientation of the crystallographic texture from one grain to another. Thus some additional force is required to move the dislocations across the barrier. Now due to cryorolling, since the grain size is reduced, there is an increase in the number of grains and overall grain boundary and therefore the size of the overall barriers for the dislocations increases and more force is required for the dislocations to cross the barrier which in turn increases the strength of the material.

ii. *More dislocation density*

Due to rolling, quite a large number of dislocations are produced. These dislocations get entangled between the grain boundary which impedes their motion and the strength gets increased.

With the increasing extent of cryorolling, more amount of dislocations get piled up within the grain boundaries and the sample starts to fracture after quite some time with increasing stress. Thus the ductility gets decreased with the extent of cryorolling at the cost of its strength.

iii. *Suppression of dynamic recovery*

There is suppression of dynamic recovery as in cryogenic temperature, the total internal energy of the atoms decreases as it is a function of temperature of the material. So the atoms kinetic energy decreases which results in the suppression of dynamic recovery.

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