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Study of change in mechanical properties of Zr2, Zr4, INCOLOY 800 and D9 materials on pilgering

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ABSTRACT
Zr2, Zr4, INCOLOY 800 and D9 are successfully used for cladding materials because of their mechanical and neurotic properties. Appropriate manufacturing process has to be chosen for these materials to precise control their mechanical properties. In this study cold working process of pilgering is chosen and the study of mechanical properties for the materials taken with prior cold work and further cold worked by pilgering route were characterized through tensile and hardness testing. While cold working Yield Strength, Ultimate Tensile Strength & Hardness increases due to work hardening but % elongation decreases due to work hardening which implies that ductility of material is reduced.
Keywords - annealing, cold-working, hardness, pilgering, tensile

I. Introduction

1.1 Different types of tubes and sections required for nuclear reactors

The materials are selected for reactor use considering the severe environment of neutron flux, neutron economy considerations, high temperature strength, corrosion resistance etc. Zirconium alloys are [1-7] used in PHWRS and BWRS while D9 Tubes are used in FAST BREEDER REACTORS [8-9]. Incoloy 800 tubes are used as heat exchanger tubes for steam generators of PHWRS. Circular, square and hexagonal sections in various sizes, manufactured by exotic materials meeting special requirements are required for different reactors.

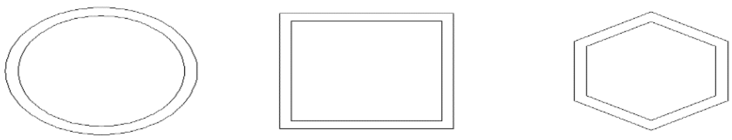


Fig.1. Different types of tubes and sections required for nuclear reactors

1.2 Process route for manufacture of pilgeredtubes[10]

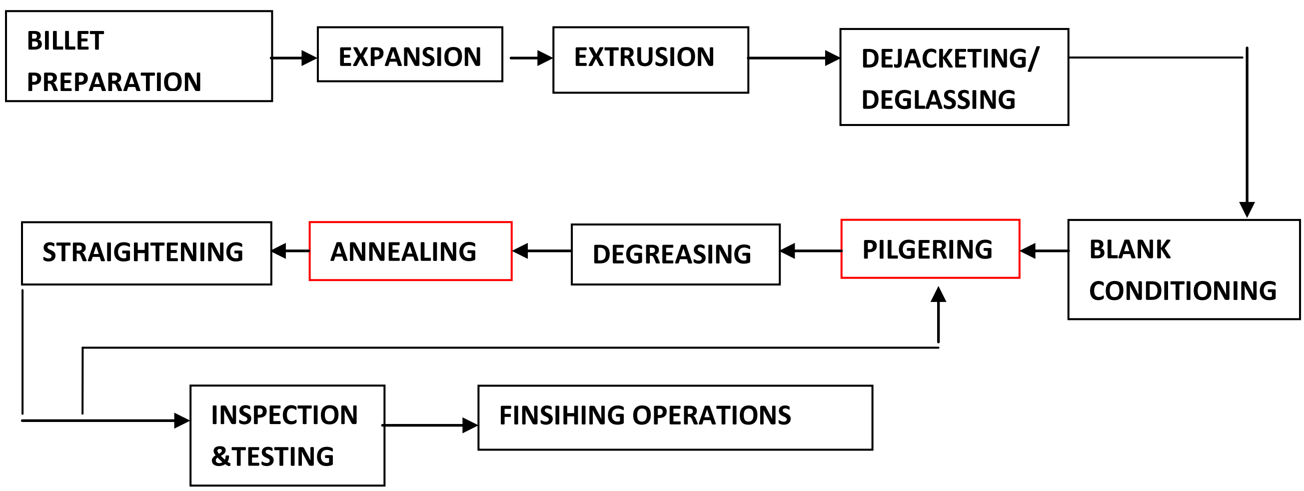


Fig: 2. Process route for manufacture of pilgered tubes

II. Experimental

2.1 Composition of materials taken

Table.1. Composition of materials taken

Grade	Zr4	Zr2	D9	INC800
Base metal	Zr(Zirconium)-98%	Zr(Zirconium)-98%	Fe (Iron)-71%	Fe (Iron)-48%
Alloying elements				
Fe(Iron)	0.22%	0.10%	Shown above	Shown above
Cr (Chromium)	0.10%	0.10%	13.5-14.5%	20%
Ni(Nickel)	-	0.05%	14.5-15.1%	32%
C(Carbon)	150 to 400ppm	150 to 400ppm	0.05 %max	0.03%
Sn(Tin)	1.3%	1.5%	-	-
Mn (Manganese)	-	-	2%	-
Mo (Molybdenum)	-	-	2.5%	-
Ti(Titanium)	-	-	0.25%	-

Each of Zr2, Zr4, INCOLOY-800, and D9 tubes which were prior cold worked are taken in annealed and pilgered conditions.

Firstly, prior cold works of the materials taken are calculated. Then, to study the changes in mechanical properties of the materials taken, tensile and hardness tests are performed and results were obtained. Finally the changes are depicted in the form of graphs and conclusions were made from analysing the results.

2.2 Tube material dimensions

Table.2 Tube material dimensions

Tube materials taken	Zr2		Zr4		INCOLOY 800		Alloy D9	
Condition	Annealed	Pilgered	Annealed	Pilgered	Annealed	Pilgered	Annealed	pilgered
G – Gauge length [N1]	50.8	50.8	50.8	50.8	95	95	40	45
OD- Outer diameter	21	14.6	17.1	15.2	19.6	19	19.6	21.4
T- Thickness	2.2	0.9	1.0	0.4	1.0	1.1	1	0.7

NOTE: All dimensions are in mm

2.3 Standard values of materials taken

Table.3. Standard values of materials taken

Specimen	Zr2	Zr4	INCOLOY 800	D 9
Tensile strength , Yield 0.2% Ksi	34.9	34	39.8	79.7
Tensile strength, ultimate, Ksi	59.9	59	87	101
HRB	99.8	89	81	96
% elongation	20	20	45	20

2.4 Calculation of prior cold work[N2]

2.4.1 Cold work

The amount of cold work is defined relative to the reduction in cross-sectional area or thickness of the metal by processes such as rolling or drawing.

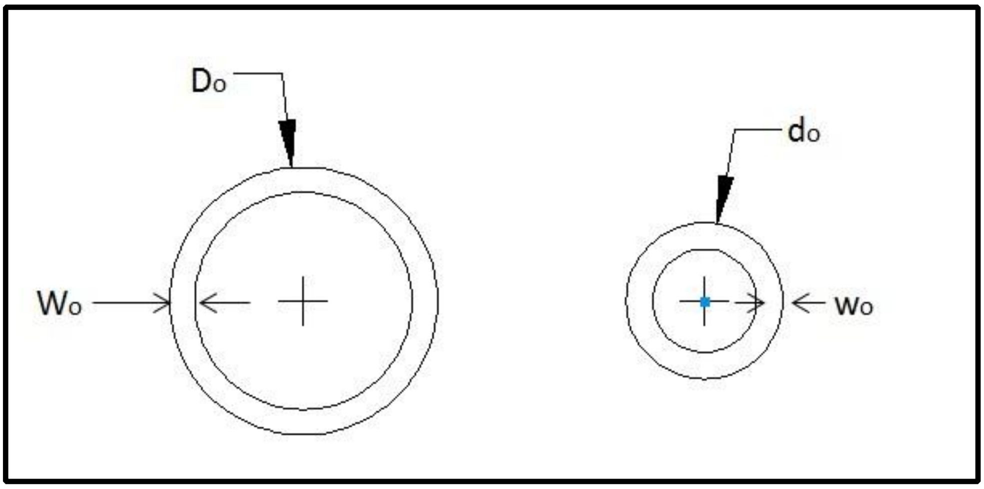


Fig: 2 Diagram representing cross-sectional areas of tubes before and after pilgering.
The amount of cold work can be calculated as follows

%CW = [(Ao - ao)/A0] x 100%

= [(DoWo-dowo)/DoWo] x 100%

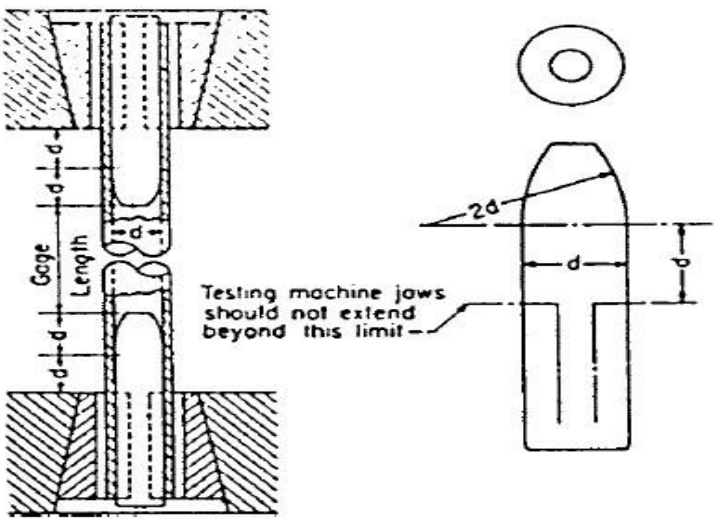
Table. 4 cold work calculation

Tube material	Zr2	Zr4	INCOLOY 800	D9
Prior cold work (%)	71	63	3	20

2.5 Tensile testing

Tensile testing, also known as tension testing, is a fundamental materials sciencetest in which a sample is subjected to a controlled tensionuntil failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongationand reduction in area. From these measurements the following properties can also be determined: Young's modulus,yield strength, and strain-hardeningcharacteristics.

2.5.1 Test specimen nomenclature



NOTE—The diameter of the plug shall have a slight taper from the line limiting the test machine jaws to the curved section.

Fig: 3 Test specimen nomenclatures

2.5.2 Standard used for tensile testing of tubes

ASTME8 / E8M-11: "Standard Test Methods for Tension Testing of Metallic Materials"

2.6 Hardness test

Rockwell Hardness test B (HRB) test is used here as these materials are annealed carbon steels.

2.6.1 Standard used for hardness (HRB) testing of tubes

ASTM E18: "Standard Test Methods for Rockwell Hardness of Metallic Materials"

3. Result

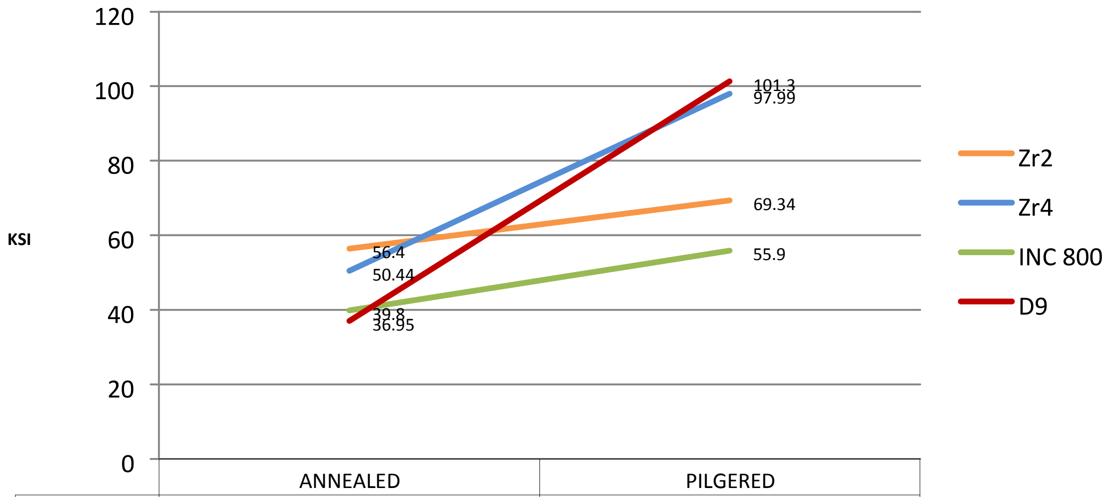
Stress-strain curves obtained from tensile testing of materials are attached in the annexure. Values obtained from tensile and hardness tests at annealed and pilgered conditions are tabulated below.

Table.5 Result

Material	Sample no.	Size	Condition	Hardness (HRB)	YS (Ksi)	UTS (Ksi)	%EL[N3]
Zr2	**8**	**21 x 2.2**	**Annealed**	**91**	**56.4**	**79.7**	**35.0**
	1	**14.6 x 0.9**	**71% cold work pilgered from 21 x 2.2**	**94.5**	**69.34**	**89.94**	**24.0**
Zr4	**2**	**17.1 x 1.0**	**Annealed**	**78.5**	**50.44**	**71.83**	**44.0**
	3	**15.2 x 0.4**	**63% cold work pilgered from 17.1 x 1.0**	**87.5**	**97.99**	**107.98**	**24.0**
Incoloy 800	**4**	**19.6 x 1.0**	**Annealed**	**75.25**	**39.80**	**88.19**	**37.0**
	5	**19 x 1.1**	**3% cold work pilgered from 19.6 x 1.0**	**78.25**	**55.90**	**90.89**	**31.0**
D9	**6**	**19.6 x 1**	**Annealed**	**76.75**	**36.95**	**87.56**	**50.0**
	7	**21.4 x 0.7**	**20% cold work pilgered from 23.5 x 0.8**	**88.75**	**101.3**	**107.8**	**25.0**

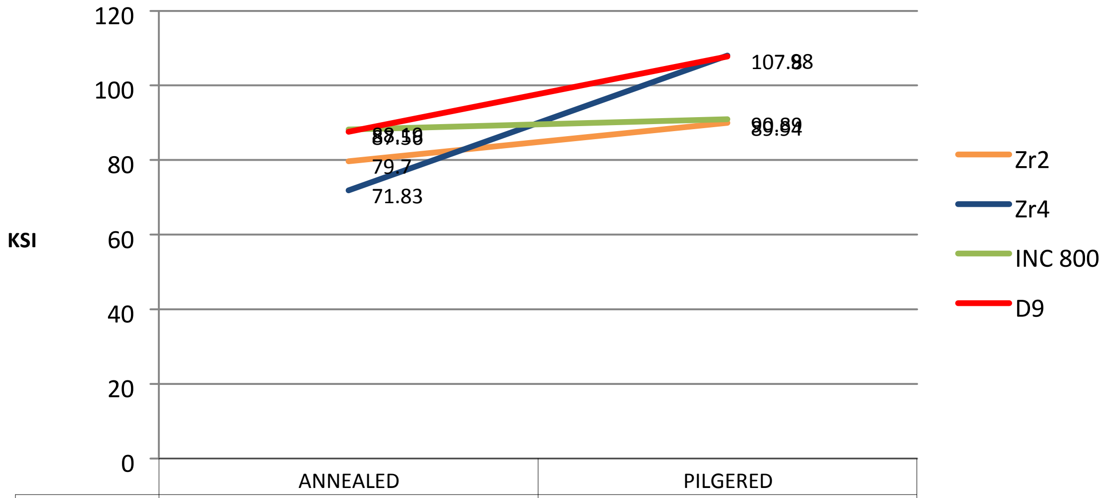
4. Graphs

4.1.1 Consolidation of variation in YS for Zr2, Zr4, INCOLOY 800 and D9 atAnnealed and pilgered conditions



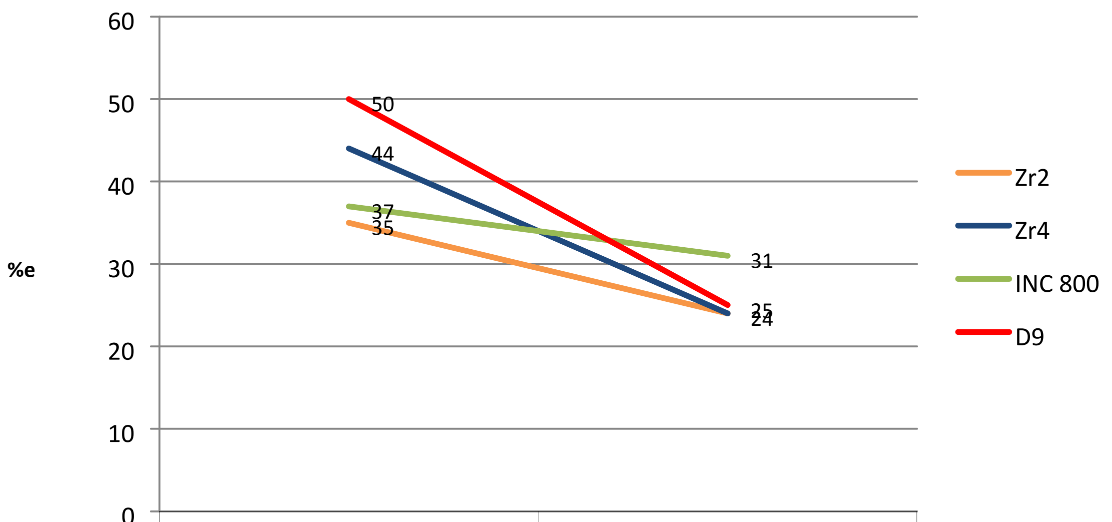
	ANNEALED	PILGERED
Zr2	56.4	69.34
Zr4	50.44	97.99
INC 800	39.8	55.9
D9	36.95	101.3

4.1.2 Consolidation of variation in UTS for Zr2, Zr4, INCOLOY 800, D9 atAnnealed and pilgered conditions



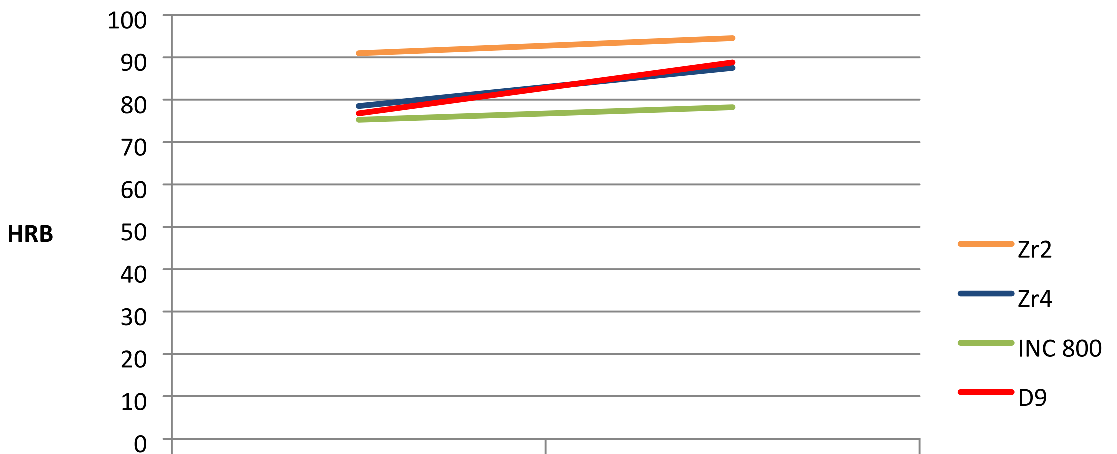
	ANNEALED	PILGERED
Zr2	79.7	89.94
Zr4	71.83	107.98
INC 800	88.19	90.89
D9	87.56	107.8

4.1.3 Consolidation of variation in %ELONGATION for Zr2, Zr4, INCOLOY800, D9 at annealed and pilgered condition



	ANNEALED	PILGERED
Zr2	35	24
Zr4	44	24
INC 800	37	31
D9	50	25

4.1.4 Consolidation of variation in HARDNESS for Zr2, Zr4, INCOLOY800, and D9 atannealed and pilgered condition



	ANNEALED	PILGERED
Zr2	91	94.5
Zr4	78.5	87.5
INC 800	75.25	78.25
D9	76.75	88.75

5. Discussion

Since pilgering is a complex process, there is a lot of scope for study and carrying out analysis. Some of those are:

- Characteristics of different materials.
- Study on work hardening.

- Kinematic study of pilgermills.
- Force calculations.
- Tribological studies.
- Spring back aspects.
- Metallurgical and micro structural studies.

Conclusions

Samples of Zr4, Zr2, D9, and INC800 were taken for tensile test & hardness test. Recorded values were tabulated and following observations were made.

1) While cold working YS, UTS& hardness increases due to work hardening.
2) % elongation decreases due to work hardening which implies that ductility of material is reduced.
3) This is in line with the theory of deformation. From the above the formability of material substantially reduces with the increase in cold work, there-by sizing / shaping of the material will not be possible. Thus intermediate annealing is carried out to regain its ductility & for further cold working.

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8. Notes

[1] Gauge length calculation

For Zr2 and Zr4: 50.8 mm
For incoloy 800: 5d = 95 mm
For D9:$5.65\sqrt{\mathrm{A}} = (5.65\sqrt{(19.6-1)1\pi}) = 45$ mm
For D9: $5.65\sqrt{\mathrm{A}} = (5.65\sqrt{(21.4-0.7)0.7\pi}) = 40$ mm

[2] % CW

$$zr_2 = \frac{(21x2.2)-(14.6x0.9)}{(21x2.2)} \text{ x } 100 = 71\%$$

$$zr_4 = \frac{(17.1x1.0)-(15.2x0.4)}{(17.1x1.0)} \text{ x } 100 = 63\%$$

$$\text{Incoloy} - 800 = \frac{(19.6x1.1)-(19x1)}{(19.6x1.1)} \text{ x } 100 = 3\%$$

$$D9 = \frac{(23.5x0.8)-(21.4x0.7)}{(23.5x0.8)} \text{ x } 100 = 20\ \%$$

[3] % e calculation

Sample no.1 $Zr_2 = \frac{62.992-50.8}{250.8} \text{ x } 100 = 24\%$

Sample no: 2: $Zr_4 = \frac{73.15-50.8}{50.8} \text{ x } 100 = 44\%$

Sample no: 3: $Zr_4 = \frac{60.96-50.8}{50.8} \text{ x } 100 = 24\%$

Sample no: 4: $\text{Incoloy} - 800 = \frac{130.81-95}{95} \text{ x } 100 = 37\%$

Sample no: 5: $\text{Incoloy} - 800 = \frac{109.22-95}{95} \text{ x } 100 = 31\%$

Sample no: 6: $D9 = \frac{67.31-45}{45} \text{ x } 100 = 50\ \%$

Sample no: 7: $D9 = \frac{49.78-40}{40} \text{ x } 100 = 25\ \%$

Sample no: 8: $Zr_2 = \frac{59.69-50.8}{50.8} \text{ x } 100 = 35\%$