Influence of Heat Treatment on Mechanical Properties of Garter Spring Made By Zirconium Alloy

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Abstract -**Garter springs are used as spacer between the coolant tube and Calandria tube in pressurised heavy water reactors (PHWR). These are made from Zirconium alloy containing 2.5% Nb and 0.5% Cu. The springs are basically manufactured by coiling a wire of cross section 1.7mm*1.0mm, which is produced by series of drawing and swaging operations using hot extruded rods of 19mm diameter. Pure Zr has lower strength, hence alloying elements are added. Nb addition gives higher strength with moderate ductility. Resilience is achieved by addition of 0.5% Cu in garter springs. It will give a very small deflection under large applied load. Apart from resilience, deflection and stiffness properties, the strength and hardness of the material are crucial in deciding the applicability of the material for this application. Heat treatment (Solutionizing and ageing) influence the properties of non ferrous alloys. Hence this project describes the influence of heat treatment on mechanical properties of garter spring made of Zirconium alloy.**

Key words- zirconium alloy; tensile strength; hardness; heat treatment.

I. INTRODUCTION

A garter spring is a coiled steel spring that is connected at each end to create a circular shape, and is used in oil seals, shaft seals, belt-driven motors, and electrical connectors.[1] The garter spring is also used as spacer between the coolant tube and Calandria tube in pressurized heavy water reactors (PHWR). This is one of the most important and critical component that goes into the reactor. The purpose of garter spring is to maintain the annular gap between Calandria and pressure tubes. The materials that are normally employed in the manufacture of garter springs are carbon steel, stainless steel etc. In pressurized heavy water reactors (PHWR), Zirconium alloy is commonly used to manufacture the garter spring.[2] Zirconium does not absorb neutrons, making it an ideal material for use in nuclear power stations whereas stainless steel and carbon steel does not. Pure Zr has lower strength, hence alloying elements are added. Nb addition gives higher strength with moderate ductility. Resilience is achieved by addition of 0.5% Cu in garter springs. It will give a very small defection under large applied load.

Zirconium can be heat treated using standard equipment and processes used for other materials with some additional considerations. Because zirconium is reactive with carbon-containing substances at elevated temperatures, it is important to remove all dirt, oils, greases, and other residues before heat treatment. A level of cleanness comparable to that used before welding is ideal.[3]

Either furnace heat treatment or localized heat treatment can be used for zirconium. Typically, electric, gas-fired, or oil-fired air furnaces are used to heat treat zirconium, but vacuum- or argon-purged electric furnaces are preferred when surface oxidation is not desirable. When using gas-fired heating, a slightly oxidizing or neutral atmosphere is mandatory. Direct flame impingement must be avoided.

Zirconium alloy 702 typically does not require stress relieving, but a stress relief heat treatment at 565 ^{0}C (1,050 ^{0}F) for 30 to 60 minutes at temperature can relieve residual stresses for machining stability, improve fatigue performance, and improve corrosion performance. [6]
Zirconium alloy 705 requires a stress relief heat treatment within 14 days after welding to prevent delayed hydride cracking. ASME Boiler and Pressure Vessel code gives guidance for heat treatment requirements of zirconium grade 705.[4]

Heat treatment is also used to enhance the surface oxide on zirconium to improve wear resistance. A typical treatment at 565 ^{0}C (1,050 ^{0}F) for four to six hours at temperature will provide an increase in near-surface hardness to about 480 on the Vickers scale, comparable to 47 Rockwell [1].
Common methods of heat treatment of zirconium alloys include, solutionizing and ageing to improve mechanical properties. [5]

II. EXPERMENTATION

A. Material

The material used for garter spring is zirconium alloy, whose composition is Zr-97%, Nb-2.5%, and Cu-0.5%. The material is taken in the form of cast ingot with about 290mm diameter. It is subjected to a series of drawing and swaging operations and extruded with the rectangular cross section of 1.7mm*1.0mm.

B. Heat Treatment

The material is subjected to intermediate annealing to produce the final shape. All the intermediate annealing between the stages has been carried out at full annealing temperature of 732C making the material suitable for further working and the finished rectangular wire is coiled in the form of springs to the required lengths. These springs are loaded into a fixture where it is compressed fully over a mandrel. About 150 No's of springs are loaded into a fixture and the fixture Is loaded into the heating chamber.

The heat treatment cycles with pre determined heating time and temperature soaking time etc are programmed in the temperature controller. After attaining the desired vacuum the heating of the material is carried out. After completing the heating cycle, the material is transferred to the cold chamber in auto mode in the shortest possible time (10 seconds) and quenching completed in oil, simultaneously purging argon into the quench chamber. The solutionised springs after checking the hardness and determining the corresponding ageing temperature are aged in the same furnace by heating for six hours under vacuum.

The garter spring in the form of wire coil of 1.7*1.0mm^2 size as been subjected to solutionizing, solutionizing and ageing at different temperatures. The heat treatment procedures are described below in table 1.

TABLE.1. Types of heat treatment processes applied to Zirconium alloy

S.No	Heat Treatment	Period Of Ageing (Hours)
1	Solutionised at732^{0}c	———
2	Solutionised at732^{0}c ageing at 440^{0}c	6
3	Solutionised at732^{0}c ageing at 460^{0}c	6
4	Solutionised at732^{0}c ageing at 500^{0}c	6
5	Solutionised at732^{0}c ageing at 520^{0}c	6

C. Mechanical Testing

The specimens for conduct of tensile test are made as per ASTM standards with the following sizes: Thickness- 0.07 inches, Breadth- 0.0445 inches, Original length- 2inches. To conduct hardness test the material is cut into 2cm length & it is subject to Vickers hardness test.

III. RESULTS

A. Tensile Properties

The specimens after different heat treatments are subjected to tensile test to determine yield strength, ultimate tensile strength and %elongation of the spring material. The results are given in the table 2.

TABLE.2. Tensile properties of zirconium alloy after various heat treatments.

S.No.	Sample	UTS (MPa)	YS (MPa)	%Elongation
1	Solutionised2	122.44	96.47	8.0
2	Solutionised & aged at 440°c (A1)	145.16	106.63	6.6
3	Solutionised & aged at 460°c(A1)	120.27	100.2	6.3
4	Solutionised & aged at 500°c(A1)	115.92	93.75	4.5
5	Solutionised & aged at 520°c(A1)	116.0	96.8	4.7

After solutionizing it is observed that the ultimate tensile strength is 122.44 MPa. From the results it is observed that the ultimate tensile strength and yield strength are increased after ageing. After ageing at 440^{0}C. The ultimate tensile strength has gone up to 145.16 MPa. Further increase in ageing temperature led to decrease in ultimate tensile strength i.e to a value of 116 MPa at 520^{0}C. Similar trends are observed in yield strength value also. The % elongation is decreased after ageing. The increase in ultimate tensile strength and yield strength after 440^{0}C ageing may be the result due to precipitation of second phase partilcles of Niobium (Nb), as Nb increases the strength of the alloy. When the ageing temperature is increased beyond 440^{0}C the strength is decreased which may be due to grain coarsening of the matrix that may takes place at high temperature.[7]

B. Hardness

The hardness data of various heat treated samples after conduct of Vickers Hardness Test are given in the table 3.

TABLE.3. The hardness data of zirconium alloy after various heat treatments

S.No.	Sample	VHN
1	Solutionised	175
2	Solutionised & aged at 440°c	262
3	Solutionised & aged at 460°c	263
4	Solutionised & aged at 500°c	260
5	Solutionised & aged at 520°c	254

From the data it is observed that hardness is increased after ageing at 440^{0}C as mentioned earlier. This may be due to precipitation hardening which takes place due to precipitation of Niobium. Ageing at higher temperature i.e. beyond 500^{0}C reduces the hardness of the material due to coarsening of grains at high temperature.

IV. CONCLUSION

- The Heat Treatment process i.e solutionizing & ageing can successfully adapted to *Zr* alloy.
- Increase in tensile strength, yield strength & hardness resulted after ageing at 440^{0}C.
- Further increase in ageing temperature may reduce the mechanical properties.

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