Preliminary Studies on Thermal Cycling of Reactor Pressure Vessel Steel

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Abstract

The reactor pressure vessel (RVP) of a pressurized water reactor (PWR) or a boiling water reactor (BWR), i.e., of a light water reactor (LWR), is made of carbon steel. The inside surface is clad with stainless steel to prevent general corrosion. These pressure vessels are expected to with-stand normal and postulated accident conditions. These vessels are installed within a concrete biological shield and the whole plant is in turn surrounded by a concrete containment building. Most of the operating experience relates to two and three loop design. The scope of this paper is to study of mechanical behavior of SA 516 grade 65 carbon steel used for steam generator application undergoing thermal cycling loading. The effect of temperature, cycle time, pre stress and no of cycle would be the varying parameters

Keywords: SA 516 Grade 65 carbon steel, Pre stress, Thermal Stress and Thermal Cycling

1 Introduction

Pressure vessels commonly have the form of spheres, cylinders, ellipsoids, or some composite of these. In practice, vessels are usually composed of a complete pressure containing shell together with flange rings and fastening devices for connecting and securing mating parts. As the name implies, their main purpose is to contain a media under pressure and temperatures: however, in doing so they are also subjected to the action of steady and dynamic support loading, piping reactions, and thermal shocks which require over all knowledge of the stresses imposed by these conditions on vessel shapes and appropriate design means to ensure safe and long life [1, 7, 8]. The ever increasing use of vessels for storage, industrial processing, and power generation under unusual conditions of high pressure, temperature and environment has given special emphasis to analytical and experimental methods for determining their operating stresses. Developments in the space, nuclear, and chemical industries have placed new demands on materials suitable for extremes in temperatures, impact, and fatigue. [1, 2].
In general, pressure vessels designed in accordance with the ASME Code, Section VIII, Division 1, are designed by rules and do not require a detailed evaluation of all stresses. It is recognized that high localized and secondary bending stresses may exist but are allowed for by use of a higher safety factor and design rules for details. It is required, however, that all loadings (the forces applied to a vessel or its structural attachments) must be considered. In reactor pressure vessels (RPVs) different materials are used for the different components (shells, nozzles, flanges, studs, etc.). Moreover, the choices in the materials of construction changed as the pressurized water reactors (PWR) products evolved [1, 2, 3, 4].

2 Experimental details

2.1 Materials

The material to be used is carbon steel SA 516 grade 65 that is used in reactor pressure vessel [2, 14]. The steel was received in the form of rectangular block. The specimens were made from these blocks to conducting the thermal cycling test. This specification covers carbon steel plates intended primarily for service in welded pressure vessels where improved notch toughness is important. Plates under this specification are available in four grades having different strength levels as follows: [2] .

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2.2 Chemical Composition

Table 1:- Chemical composition of SA 516 steel [2]

Type of steel	**C**	**Mn**	**Si**	**Cr**	**Ni**	**P**	**S**
SA 516 Grade65	0.24	0.85–1.20	0.15–0.40	-	-	0.025	0.025

2.3 Mechanical Properties

Table 2:- Tensile Requirements [2]

	Grade			
	55	60	65	70
Tensile strength,[MPa]	380–515	415–550	450–585	485–620
Yield strength, min, [MPa]	205	220	240	260

2.4 Test Apparatus

The stresses on reactor pressure vessel wall in power plants include the internal steam pressure, cyclic thermal stresses, residual stresses, and external loading stresses. Cyclic thermal stresses are generated during plant startup and shutdown because of large change in temperature. External loading (bending) stresses are the biggest unknown, and may be most deleterious. Such stresses arise because of plant design and construction.

To try and simulate the conditions for a reactor pressure vessel used in power plants, a simple three-point loading, bent-beam test apparatus is used (fig.1) [5]. On a specimen thus loaded, there is a stresses gradient through the thickness, varying from a maximum tension stress on the top (convex) surfaces to bottom (concave) surface. The stress also varies along the length; it is a maximum at the center and decreases linearly to zero at the outer supports.

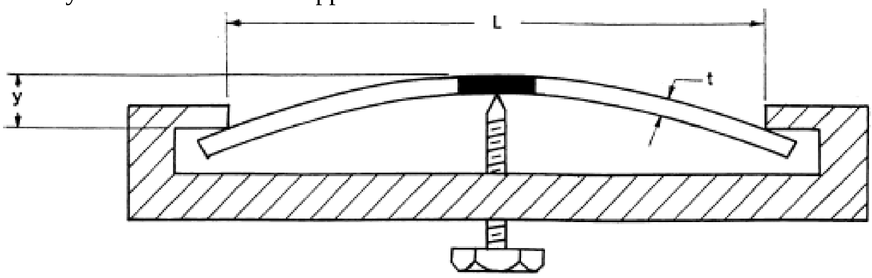


Figure 1:- Schematic of three-point-loaded, bent-beam test Apparatus [5]

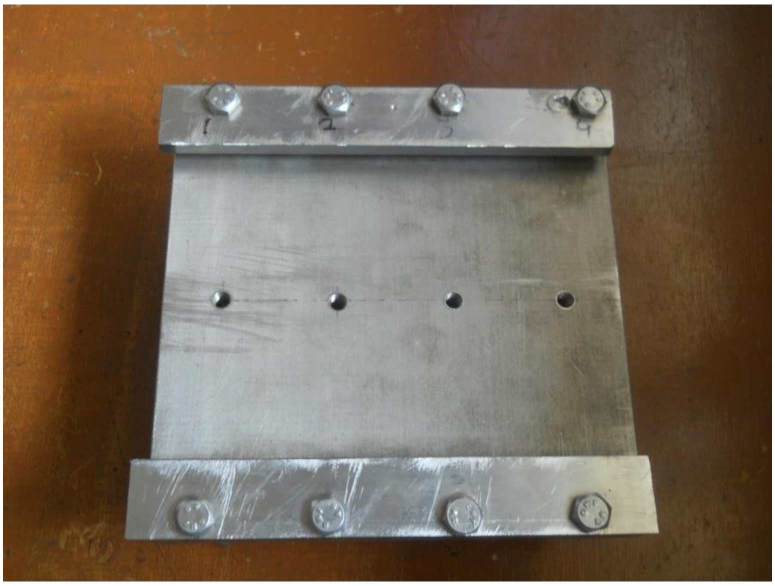
The elastic stress at the midspan on the outer fibers is given by:

$$\sigma = \frac{6Ety}{L^2} \qquad (1)\ [5]$$

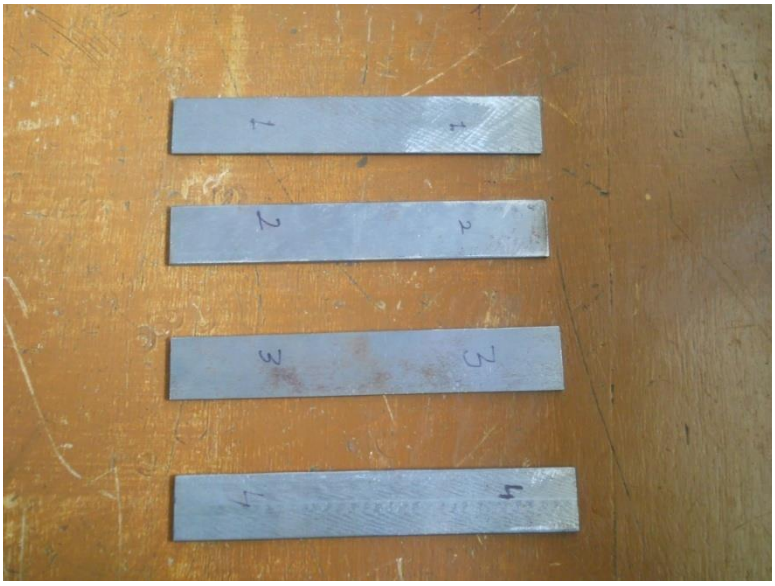
Where σ the maximum stresses, y is the displacement of the outer fiber normal to the surface at the center of the specimen, E the modulus of elasticity, t the specimen thickness, and L the distance between the outer supports.

A simple test apparatus made of type 304 L stainless steel was constructed m- fig. 2(a). It consisted of a 13.0 mm thick plate to which an L – bracket was bolted to each side. Four ¼ - 20 threaded holes were placed along the canter of the plate. These holes were fitted with hex head setscrew, which are turned against the center of the specimen displacement (y of Fig. 1) for a given stresses estimated from equation (1). The displacements at the center of the specimen are to be determining using a dial gauge.

Dimensions of bent-beam apparatus:
Plate = 155 mm x 155 mm x 13 mm
Four specimens of dimensions 132 mm x 23 mm x 3.5 mm

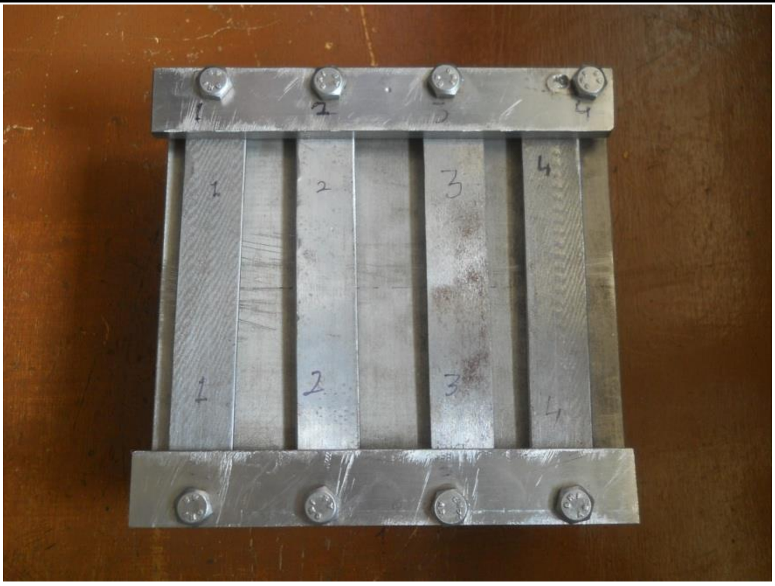


(a)

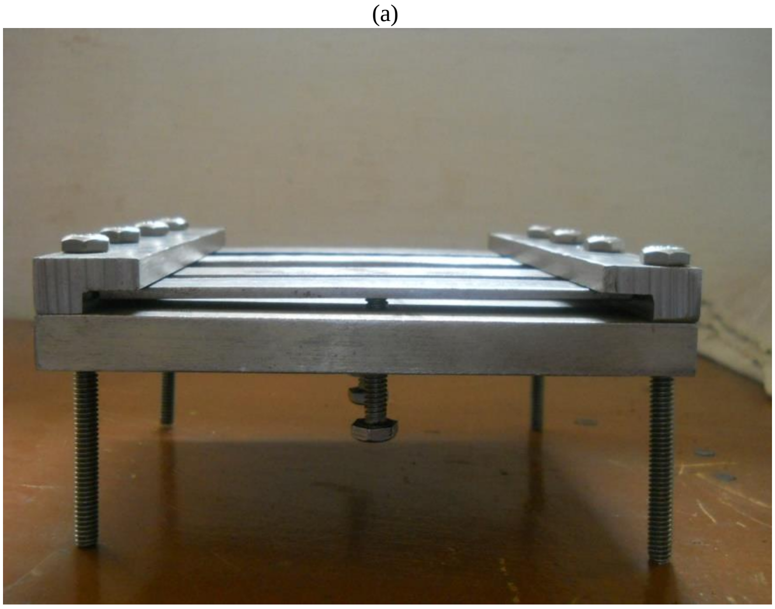


(b)

Figure 2:- (a) Three -point-loaded, bent-beam test apparatus, (b) Four specimens of SA 516 grade 65



(a)



(b)

Figure 3:- (a) & (b) Bent-beam test apparatus containing four samples

The samples were then loaded in a three-point bending fixture with set-screws, as shown in Fig. 1. The displacement, y, to be applied at the centre of the specimen by the set-screw corresponding to the elastic bending stress, σ was calculated from the equation 1

After loading, the specimens will be thermally cycled between room temperature and 300^0C. The test fixtures with the samples were first held at 300^0C for 21 h in a furnace, then removed and cooled to room temperature for about 3 h in still air, and subsequently reintroduced into the furnace to repeat the cycle. The high starting stresses and the high hold temperature were used for the purpose of acceleration as in the case of stress-rupture tests.

3 Result and discussion:

The bent-beam apparatus and the specimens of material carbon steel SA 516 grade 65 both are completed. Now the specimens with apparatus are to be placed in furnace for simulating the thermal cycling environment after which the specimens will be taken out from furnace and as well as from set up and then mechanical properties of these specimens will be find out.

Based on literature review [5] the following parameters are to be used for conducting thermal cycling test for RPV steels are shown on table 3:

Table 3:- Thermal cycling test for reactor pressure vessel steel SA 516

Specimen no.	Y (mm)	Pre stress (MPa)	Initial Temp (^{0}C)	Final Temp (^{0}C)	Heating time (hours)	Cooling time (hours)	No. of cycles
1	0.2	75.94	28	300	21	3	20
2	0.4	151.87	28	300	21	3	20
3	0.6	227.81	28	300	21	3	20
4	0.8	303.74	28	300	21	3	20

After thermal cycle test macro hardness, tensile test, and ductility are to be find out. The results of samples are given in table no 4 and fig no 4-8:

Table 4:- Thermal cycling test results

Sample Type	Pre- Stress Mpa	Hardness VHN	UTS MPa	% Elongation
Sample-1	75.94	203	504.2	28.4
Sample-2	151.87	210	515.17	27.6
Sample-3	227.81	213	538.4	26.8
Sample-4	303.74	220	551.51	24.4
Base Metal	0	198	490.9	39.2

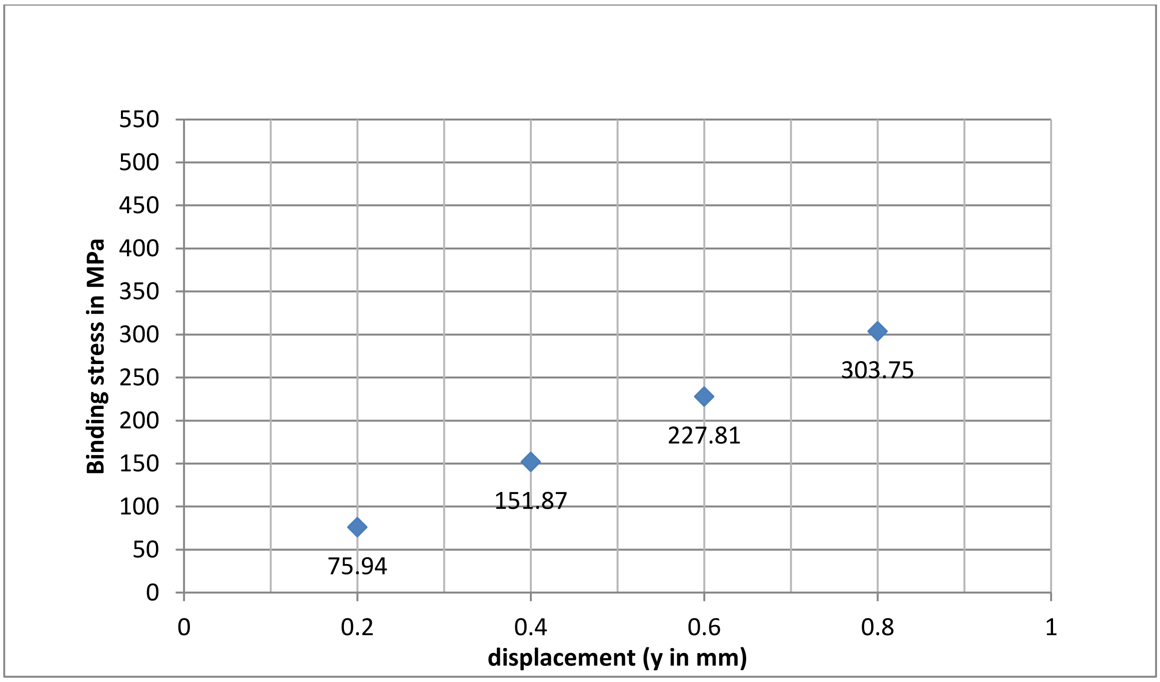


Figure 4:- Graph between displacement and bending stress

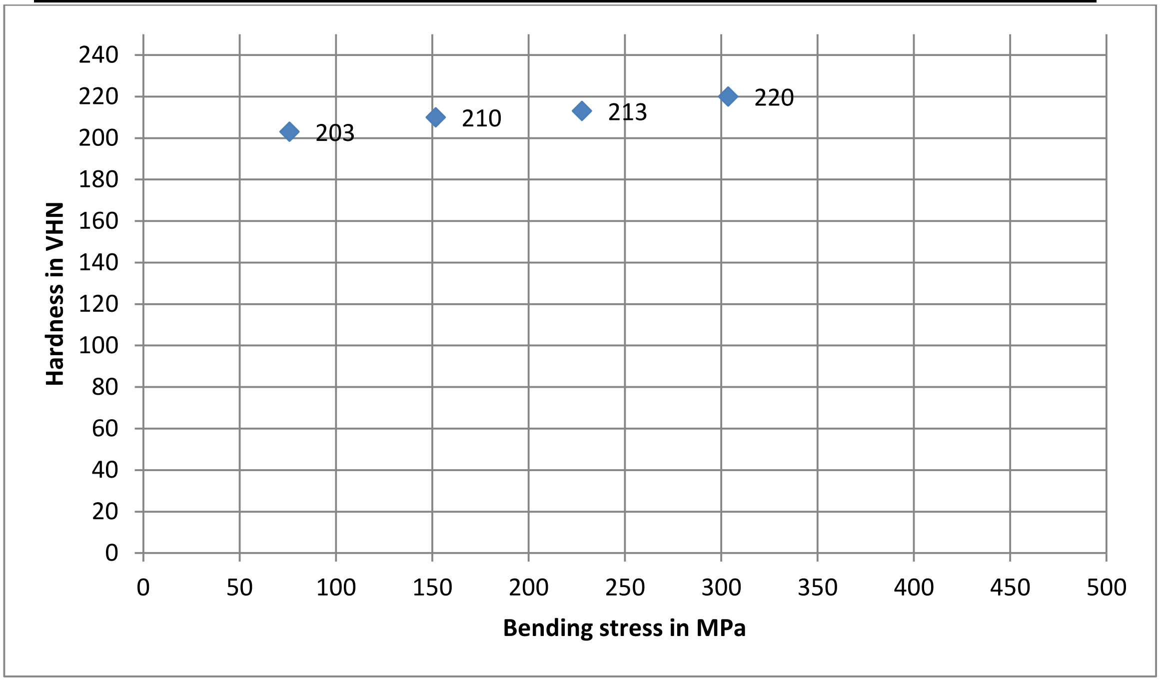


Figure 5:- Graph between bending stress and hardness

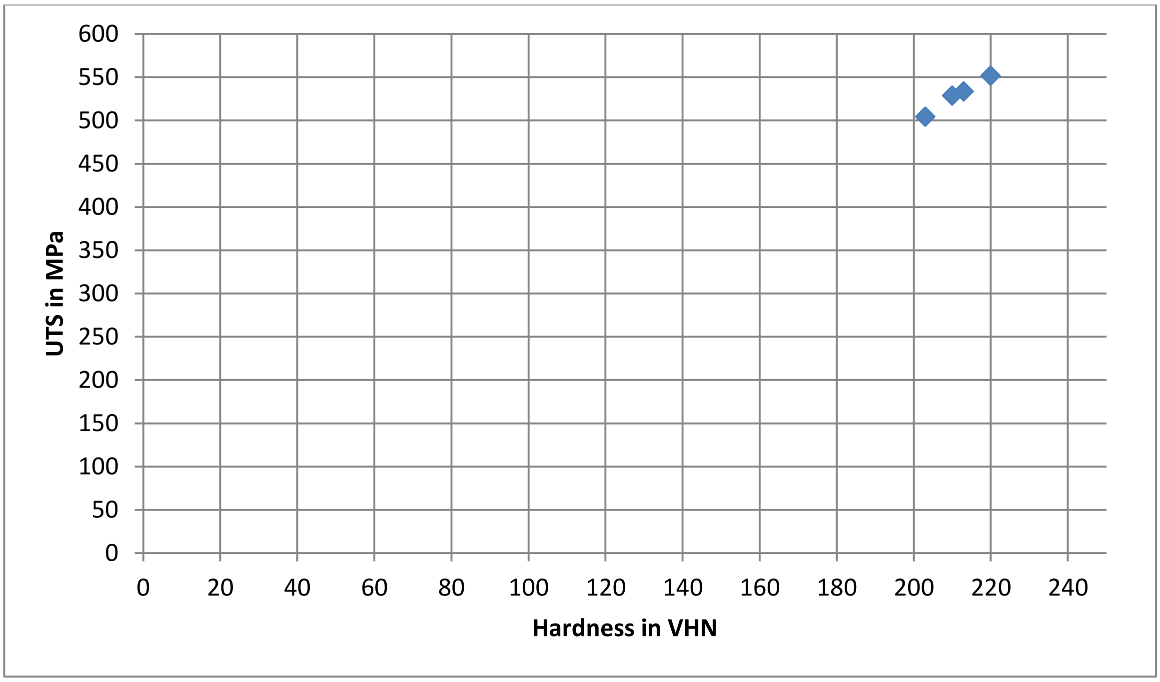


Figure 6:- Graph between hardness and UTS

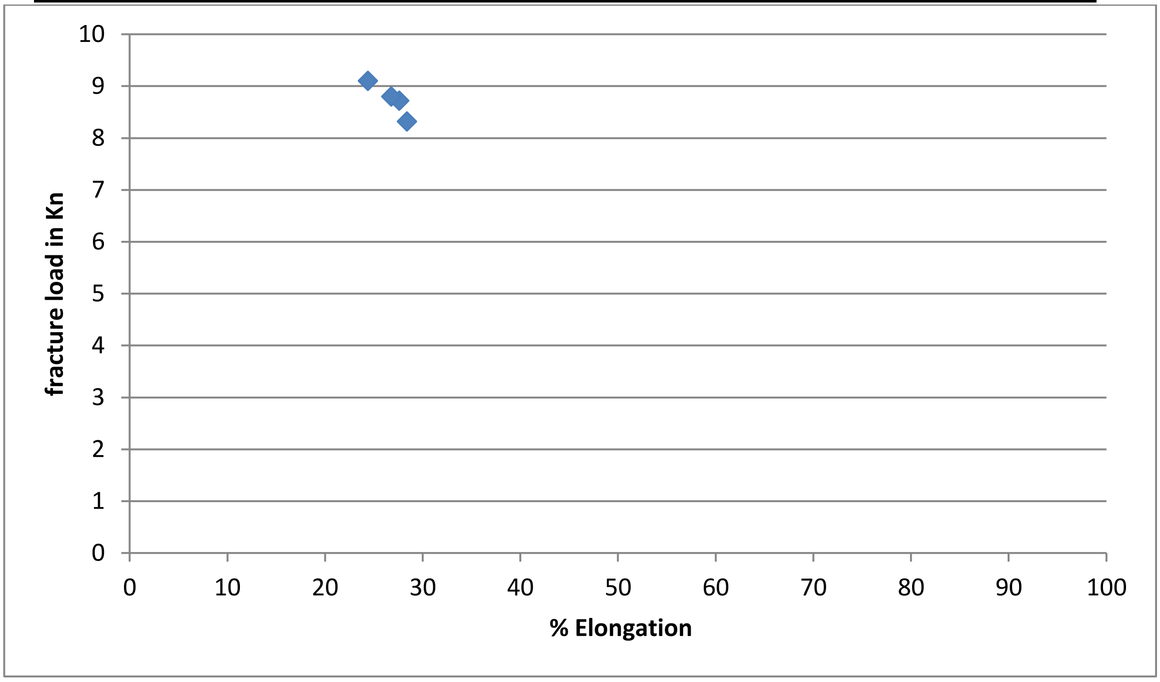


Figure 7:- Graph between % elongation and fracture load

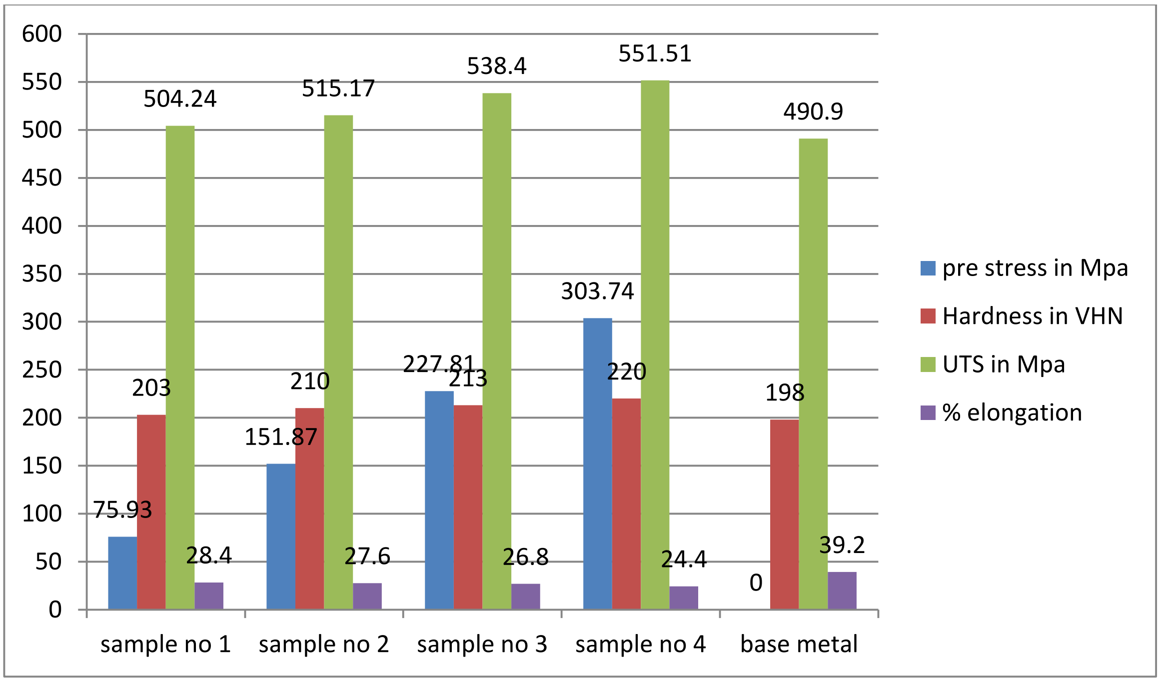


Figure 8:- Comparisons of properties between four samples and base metal

4 Conclusions

After conducting the thermal cycling experiments on SA 516 carbon steel grade 65 samples the following conclusions can be made:

- The ultimate tensile strength of samples increases by increasing the pre-stress.
- The hardness of carbon steel samples increase as the value of pre-stress increase.

- Due to thermal loading the ductility of samples decreases.
- For preventing brittle behaviour of carbon steel the value of pre-stress and thermal stress should be low as possible.

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