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Ultrasonic Characterization of Austenitic Stainless Steel in Thermal Variations

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ABSTRACT

This work focuses on the ultrasonic characterization and hardness of Austenitic stainless steel in thermal variation. The sample which was heat treated at 1050^{o}C has the highest hardness value and plays a dominant role in dispersion of carbides. Shear wave velocity and hardness show similar trend in variation with temperature. The effect of volume expansion would be to decrease the elastic constants.

Keywords: Austenitic stainless steel, Ultrasonic velocity, Hardness, Elastic constants

I. INTRODUCTION

Stainless steels are steels with high percentage of Chromium [1].On the basis of the predominant phase constituent of the microstructure Stainless steel are divided into classes and are described as Martensitic, ferritic, austenitic and duplex [2]. Austenitic stainless steel is one of the structural materials which are commonly used in wide variety of industries including power, chemical and nuclear. Excellent resistance to corrosion, adequate mechanical properties, and good fabric ability are the properties exhibited by these steels. Chromium carbides which are formed by the interactions of carbon and Chromium atoms were suggested to be relevant mechanism in the case of austenitic stainless steel[3].The 316 austenitic stainless steel contains 16-18 weight percent of Chromium. Their corrosion resistance is very high compared to that of 304 grade due to it's high content of Molybdenum. As the content of carbon is very little, this alloy is suitable for welding[4,5]. The characterization of the metals tested at STC is supposed to have large variation under various temperatures[6-9].The significant property of the ultrasonic technique is determination of material properties without harming the structure of the material[10].Hence the objective of this paper is to characterize the 316 austenitic stainless steel at different temperatures by measuring hardness and elastic constants by ultrasonic testing.

In the present study austenitic stainless steel test specimens are subjected to thermal variations for 15 minutes holding time followed by water quenching.

II. METHODS AND MATERIAL

Table.1. Characterize the samples of austenitic 316 grades stainless steel obtained in the form of 1cm length, 1cm breadth and 3mm thickness.

Table.1 Chemical composition of austenitic stainless steel

Element	Wt %
C	0.055
Si	0.75
Mn	1.5
P	0.02
S	0.004
Cr	16.4
Ni	13.9
Mo	2.3
Ti	0.08
N	0.0084
Al	0.021
Co	0.013
Nb	0.06

The samples were heated in an Electric muffle furnace to 1000°C, 1050°C, 1100°C, 1150°C and 1200°C for 15 min followed by water quenching. There was no special protective environment during heat treatment. By the contact pulse echo method ultrasonic tests were performed and ultrasonic velocity was determined. Density of the samples was determined by Archimedes principle. By using ultrasonic longitudinal velocity. Shear velocity, and density Elastic constants were calculated from the relations given as follows [11-13]

$$E = [\rho V_S^2 (3V_L^2 - 4V_S^2)] / (V_L^2 - V_S^2)$$
$$G = \rho V_S^2$$
$$K = \rho (3V_L^2 - 4V_S^2) / 3$$
$$\nu = (V_L^2 - 2V_S^2)/[2 (V_L^2 - V_S^2)]$$

Where E, G, K, ν, ρ, V_L and V_S represents Young's modulus, Shear modulus, Bulk modulus, Poisson's ratio, Density, Ultrasonic longitudinal velocity and ultrasonic shear velocity.

III. RESULTS AND DISCUSSION

The important parameter which is required for non-destructive technique for material characterization is ultrasonic velocity. Longitudinal and shear wave velocity measurements were made in 316 grade austenitic stainless steel specimens for different temperature. The variation of hardness with different heat treatment and the variation of ultrasonic velocity with different temperature are reported in table.2.

Table.2. Ultrasonic velocity and hardness of AISI 316 austenitic stainless steel in thermal variations

Specimen	Heat Treatment	Longitudinal Velocity (m/s)	Shear Velocity (m/s)	Microhardness (VHN)
D1	None	5906	3207	194
D2	1000°C	6043	3014	156
D3	1050°C	5967	3176	208
D4	1100°C	5928	2934	160
D5	1150°C	5916	3015	173
D6	1200°C	5963	3027	178

D1, D2, D3, D4, D5, D6 represents the samples which are in received condition and heat treated at 1000°C to1200°C.

From the table it is clear that hardness decreases when it is heated to a temperature of about 1000°C and increases for temperature about 1050°C by 52 HV and further 50°C rise in temperature leads to decrease in hardness by 48 HV and the hardness increases for the temperatures 1150°C and 1200°C. Depending on the composition there may be different effects on hardness. Even though Molybdenum is a strong carbide forming element[14], it's weight percent is very less compared to that of Chromium in 316 grade austenitic stainless steel. The highest Chromium content of 316 grade austenitic stainless steel has the property of forming carbides like $(FeCr)_3C$, Cr_7C_3, $Cr_{23}C_6$ and the fine dispersion of carbides is responsible for the increase in hardness and wear resistance[15]. The variation in longitudinal wave velocity and shear wave velocity for 316 grade stainless steel are correlated with hardness for different temperature and are presented in Fig.1.

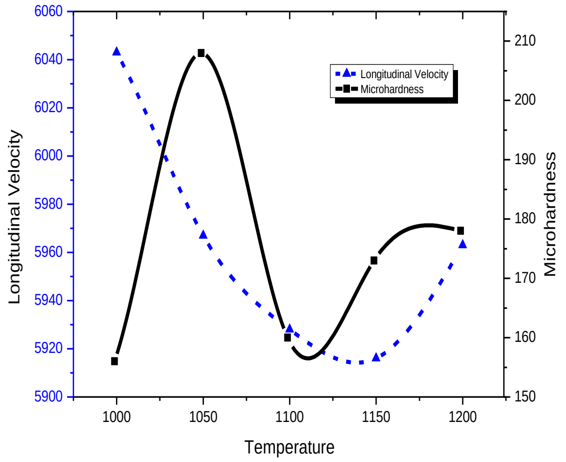

Fig.1(a)

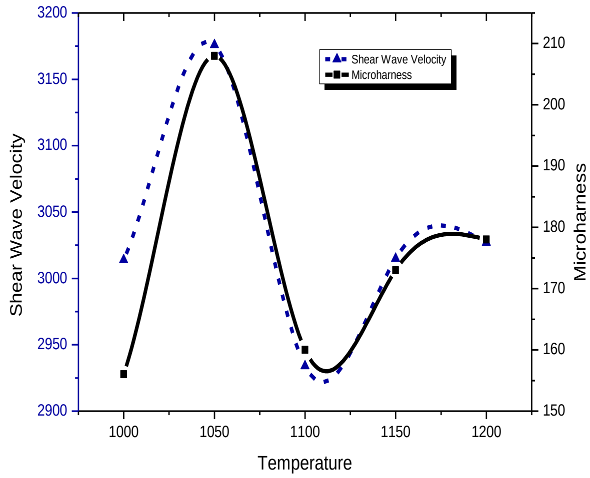

Fig.1(b)

Figure 1 : Variation in Ultrasonic Velocity and hardness.

Longitudinal wave velocity decreases exponentially with temperature upto 1050°C and shows an increasing trend for higher temperature and both longitudinal velocity and hardness shows opposite trend [fig.1a]. The retardation of recrystallization causes decrease and partial recrystallization causes increase. But the shear wave velocity and microhardness always changes with concisely trend and which implies that the hardness is mostly dependent on shear wave velocity [fig.1b]. The rise and fall of shear wave velocity and hardness to alternate 50°C is quite interesting and to explore the reason behind requires further study with less temperature interval.

To study the influence of temperature on elastic constants of 316 grade austenitic stainless steel the elastic constants were measured from ultrasonic velocities and are tabulated in table.2.

Table.3. Elastic constants of austenitic stainless steel AISI 316 in thermal variation

Specimen	Heat Treatment	Young's Modulus(GPa)	Bulk Modulus(GPa)	Shear Modulus(GPa)	Poisson's Ratio
D1	None	209	167	81	0.29
D2	1000°C	179	192	71	0.33
D3	1050°C	206	175	79	0.30
D4	1100°C	180	186	67	0.33
D5	1150°C	189	180	71	0.32
D6	1200°C	191	184	72	0.32

The trend of change in values with respect to temperature for Young's modulus and shear modulus is same in all the samples from D1 to D6. Poisson's ratio for all the samples lies between 0.29 and 0.33. The bulk modulus of the sample D2 is higher than that of all the samples. The variation in the elastic constants with respect to the temperature can be seen from Fig.2.

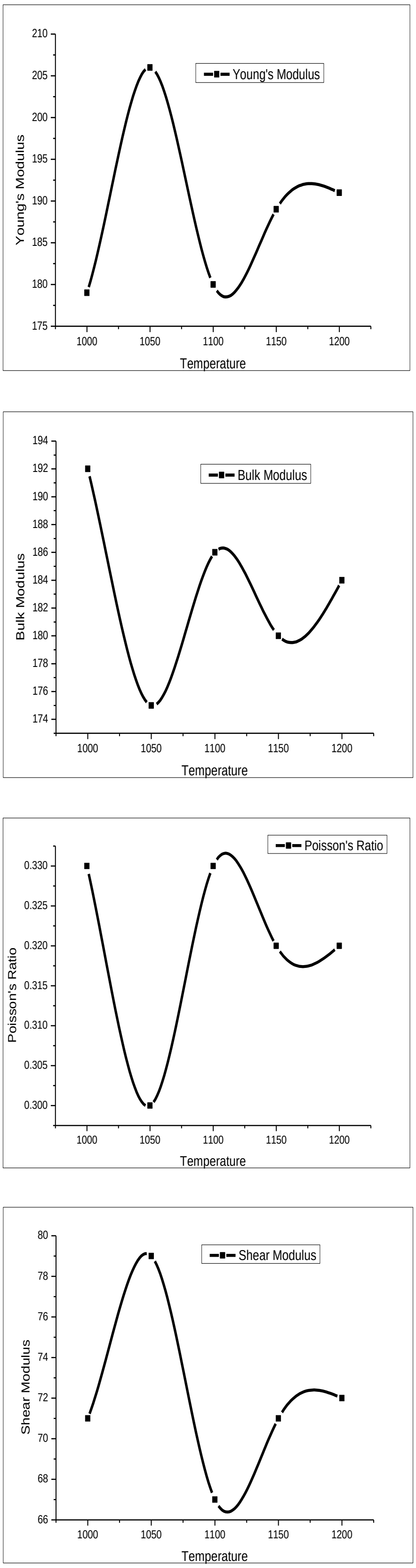

Figure 2 : Variation in Young's Modulus, Shear Modulus, Bulk Modulus and Poisson's Ratio of AISI 316 grade Stainless Steel with temperature.

When we compare the plots the bulk modulus shows an opposite effect to Young's modulus and shear modulus and is in the same trend of Poisson's ratio. Hence it is known from the figures that when the Young's modulus and shear modulus are high bulk modulus is low. This indicates the basic phenomenon of physics that an elongation creates thinning of thickness.

IV. CONCLUSION

All the samples studied using ultrasonic Non-destructive testing shows good results with more or less accurate values. The sample D3 has highest hardness value and it is clear that there is a fine dispersion of carbides at the temperature of 1050^{o}C for 15 min holding time. These carbides prevent softening on tempering and plays a major role in hardening.

The correlation studies on ultrasonic longitudinal and shear wave velocity with hardness indicate that the longitudinal velocity plays a major role in the extent of sensitization than shear velocity. As per the theoretical prediction based on elastic continuum models and lattice dynamics. The decrease in elastic constants leads to the expansion in volume [16]. This is observed in our results. The present experiment finds a solution for the characterization of materials as a function of temperature.

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