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Microstructure and It's Effect to Ultrasonic Velocity of Austenitic Stainless Steel in Thermal Variations

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Abstract*— Ultrasonic velocity of Austenitic stainless steel test specimens held at 1000°C for 10, 20, 30, 40, 50 minutes period and later water quenched were found to be strongly influenced by the microstructural features. Hardness is mostly dependent on shear wave velocity. Both longitudinal and shear wave velocity is needed for material characterization.
***Keywords*— Austenitic stainless steel, Heat treatment, Microstructure, Ultrasonic Velocity, Hardness, Elastic constant**

I. INTRODUCTION

Stainless steels are steel having highest percentage of chromium having different types such as austenitic, ferritic, Martensitic or duplex. The Fe-based alloys having the chromium content of at least 10.5% are known as Austenitic stainless steel. It has the property to prevent corrosion and high toughness. About 16-18 percent of chromium content is present in the 316 grade Austenitic Stainless steel. When compared to 304 grade Austenitic Stainless steel 316 grade has a very high corrosion resistance because of it's high molybdenum content. This 316 grade Austenitic Stainless steel is suitable for welding due to the less content of carbon[1]. 316 grade Austenitic Stainless steel founds it's applications in many industrial components, food preparation equipment particularly in chloride environments: It is also used in architectural paneling, railings and trim, boat fittings, chemical containers and heat exchangers[2].Non destructive evaluation technique should be done for the long period usage of the materials in full safety[3]. Among the various non destructive techniques Ultrasonic non destructive technique plays a dominant role in material characterization[4,5].The information about the microstructure, mechanical properties, thermo mechanical history of the material etc are provided by means of ultrasonic NDT technique[6]. In the present study specimens with different microstructures are generated in 316 grade Austenitic stainless steel test specimens by heating them at 1000°C for different holding times, followed by water quenching. The changes in ultrasonic velocity are used to characterize the variation in microstructure due to heat treatment. Elastic constants of these heat treated test coupons were also estimated from the ultrasonic velocities. Correlation between the ultrasonic velocities and elastic constants was also studied.

II. MATERIALS AND METHODS

The chemical composition of investigated Austenitic stainless steel is given in table.1.
TABLE 1

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

CHEMICAL COMPOSITION OF AUSTENITIC STAINLESS STEEL

The specimens were obtained in the form of 1 cm length, 1 cm breadth, and 3 mm thickness Test specimens were heated in an electric muffle furnace to 1000°C and held at this temperature for 10,20,30,40,50 minutes followed by water quenching. Microstructure of the specimens was examined after chemical etching in Beraha's colour etchant. Ultrasonic tests were performed by the contact pulse echo method, and the Ultrasonic velocity was determined. Archimedes principle is used in finding the density of the samples. Knowing the values of ultrasonic longitudinal velocity, shear wave velocity, and density, Elastic constants were calculated from the relations given as follows[7,8]

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

$G = \rho V_S^2$

$K = \rho (3V_L^2 - 4V_S^2) / 3$

$\nu = (V_L^2 - 2V_S^2)/[2 (V_L^2 - V_S^2)]$

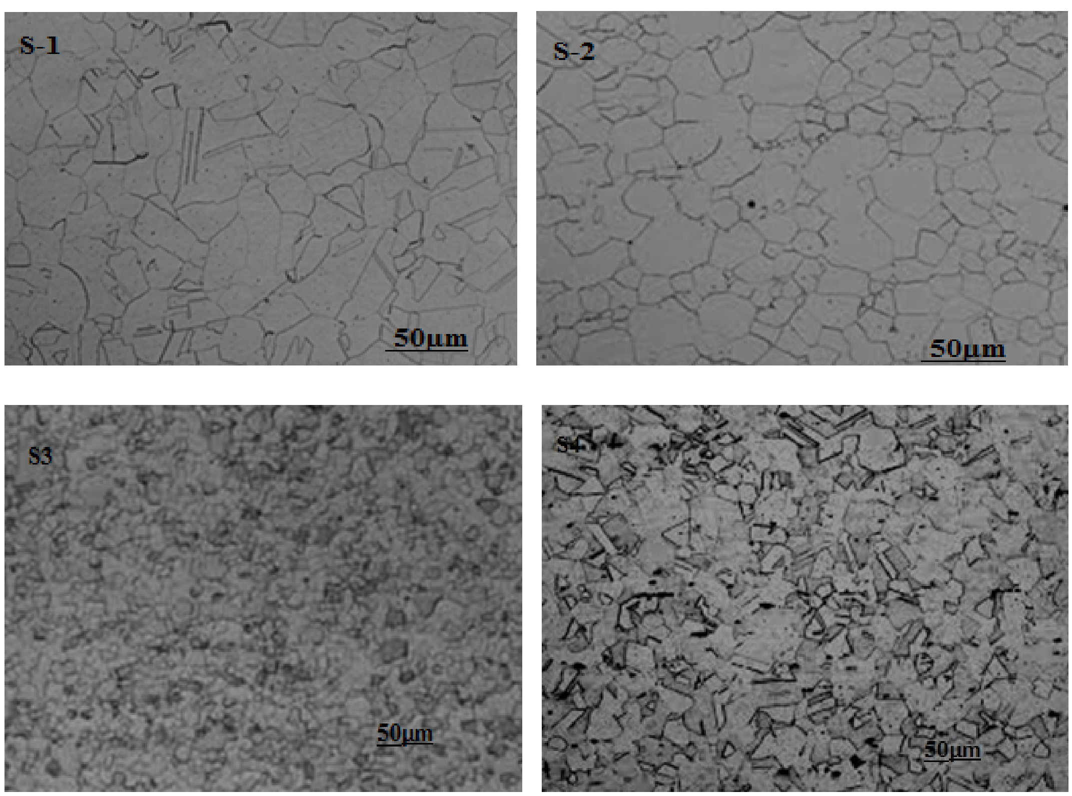
Where E, G, K, ν, ρ, V_L and V_S represents Young's modulus, Shear modulus, Bulk modulus, Poisson's ratio, Density, Ultrasonic longitudinal velocity and ultrasonic shear velocity. Vicker's hardness tester is used for the determination of hardness.
Density is determined by using Archimedes principle.

III. RESULTS AND DISCUSSIONS

The change in microstructure of Austenitic stainless steel with respect to the heat treatment, The effect of microstructure on ultrasonic velocity and hardness and the correlation of ultrasonic velocity with hardness and Elastic constants were discussed.

A. Microstructural Analysis

The variation in the microstructure occurred in the austenitic stainless steel specimens at 1000°C for different exposure period can be seen from the fig 1.The microstructure of austenitic stainless steel are affected by the two important attributes such as heat input and cooling rate[9]. heat Chemical composition, degree of prior, Deformation, grain size, aging temperature and time are the metallurgical factors which influences the sensitization behaviour of austenitic stainless steel. Sensitization occurs at temperatures between 500°C to 900°C [10].Alloy element, degree of temperature, and time of heat exposure are the causes for sensitization[11]. The sensitization is caused by carbide precipitation at the grain boundaries. The results of microstructural examination are depicted in fig 1. The sample which was unaffected by annealing shows a step structure having no precipitation[S1]. As there is no remarkable change from S1, S2 (aged at 10 min) also has no precipitation. As the annealing time increases we observe slight increase of carbide precipitation for 20 min annealing time (S3). From S4, and S5 we observe the increase in grain size which may be due to the precipitation of the carbide, but the grains are not completely surrounded by the precipitation. S6 also shows the dual structure and half of the grains are surrounded by precipitation of carbide.



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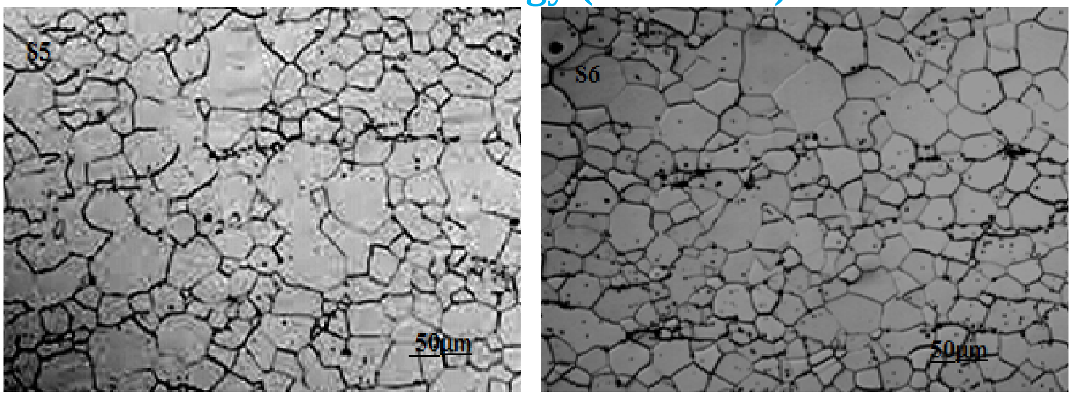

Fig.1. Microstructure of AISI 316 Austenitic stainless steel heat treated at 1000^{o}C for different holding time ; (S1) as received, (S2) 10 min , (S3) 20 min, (S4) 30 min, (S5) 40 min, (S6), 50 min.

B. The Effect Of Microstructure On Ultrasonic Velocity And Hardness

Longitudinal and shear wave velocity measurements were made in AISI 316 grade Austenitic stainless steel specimens annealed at 1000^{o}C followed by water quenching for 10 minutes to 50 minutes, and the results are tabulated in Table.2.

TABLE 2 ULTRASONIC VELOCITIES AND HARDNESS OF THE HEAT TREARED SAMPLES WITH DIFFERENT HOLDING TIME OF AISI 316 GRADE AUSTENITIC STAINLESS STEEL

Specimen	Heat treated at 1000^{O}C	Longitudinal Velocity m/s	Shear Velocity m/s	Microhardness VHN
S1	None	5906	3207	182
S2	10 min/water quenching	5965	3278	188
S3	20 min/water quenching	6046	3189	169
S4	30 min/water quenching	5972	3265	176
S5	40 min/water quenching	5930	3215	172
S6	50 min/water quenching	5915	3254	179

Longitudinal and shear wave velocity measurements were made in AISI 316 grade Austenitic stainless steel specimens annealed at 1000^{0}C followed by water quenching for 10 minutes to 50 minutes, and the results are tabulated in Table.2. It is noted that in the case of AISI 316 grade Austenitic stainless steel, the variation of longitudinal velocity with different holding time at a temperature of about 1000^{0}C exhibited a slight increase by 59 m/s for 10 min aging followed by increase of 81 m/s for 20 min holding time. This increase may be due to the lack of precipitation. There is a drop in the longitudinal velocity for 30 min aging by 74 m/s followed by the decrease of 42 m/s. for 40 min aging and the decrease of 57 m/s for 50 min holding time. This is similar to the results of C.Hakan Gur ,that increase of grain size may lead to the decrease of sound velocity[12]. It is seen from the fig 1. that the grain growth starts at S4 and from S4 onwards Ultrasonic velocity starts to decrease.It is interesting to note that the variation in shear wave velocity with aging time indicates that for every 10 min of aging time there is rise and fall. The change in shear wave velocity is almost different as compared to that of longitudinal velocity. From the table it is clear that the sample D4 has the highest hardness value. The highest hardness value for the sample D4 may be due to the following reasons. The major contribution in the hardness of stainless steel is from Chromium carbides[13] The highest chromium content(16.4%) of 316 grade austenitic stainless steel has the property of forming carbides like $Cr_{23}C_6$ and the fine dispersion of carbides is responsible for the increase in hardness and wear resistance[14].. Next to chromium Nickel occupies the second place of (13.9%) in 316 grade austenitic stainless steel. Nickel is an austenite promoting element [15]. The dissolution of nickel may increase the hardness. For sample D4 there may be fine dispersion of carbides and fine dissolution of nickel.

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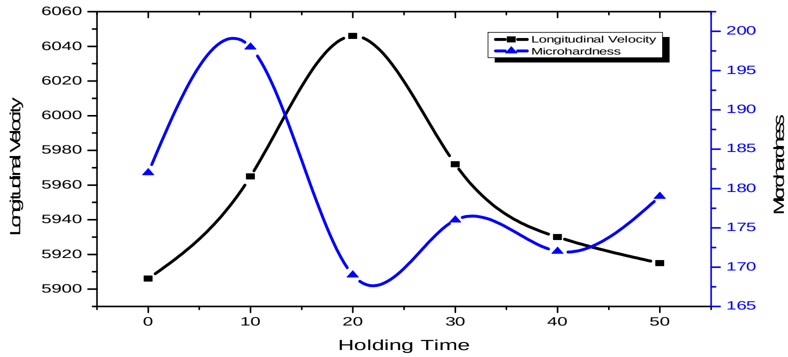

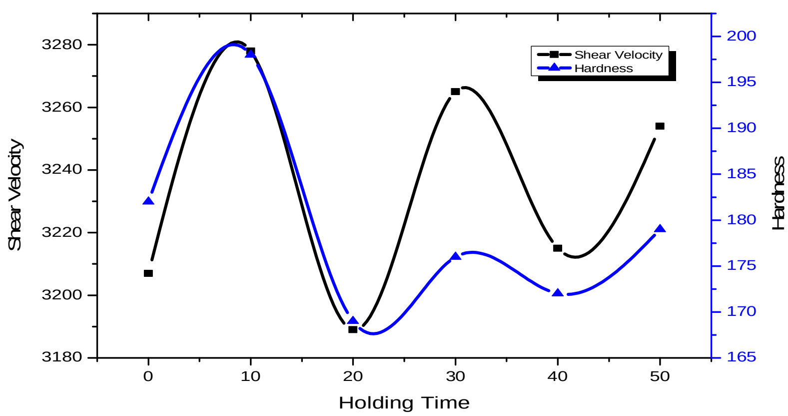

Fig. 2. Variation in ultrasonic velocity and hardness of AISI 316 Grade Austenitic stainless steel.

The variation in the longitudinal wave velocity and shear wave velocity for 316 grade stainless steel are correlated with hardness for various holding times at 1000^{o}C and are presented in fig. 2. Longitudinal velocity increases exponentially up to 20 min aging time and shows an decreasing trend, when there is an increase of holding time. Both longitudinal wave velocity and hardness shows opposite trend. The retardation of the re-crystallization causes decrease and partial re-crystallization causes increase. But the shear wave velocity and hardness always changes with concisely trend and which implies that hardness is mostly dependent on shear wave velocity and this is similar to the results of Lukomski and stepinski[16].

C. Elastic Constant

To study the influence of aging on elastic constants of 316 grade Austenitic stainless steel, the elastic constants were measured from the ultrasonic velocities and the values are tabulated in table 3.

TABLE 3 ELASTIC CONSTANTS OF AISI 316 GRADE AUSTENITIC STAINLESS STEEL AT DIFFERENT HEAT TREATMENT

Specimen	Heat treatment	Young's Modulus	Bulk Modulus	Shear Modulus	Poisson's Ratio
D1	None	209	167	81	0.29
D2	10min	216	168	84	0.28
D3	20min	208	181	80	0.30
D4	30min	215	169	84	0.30
D5	40min	210	171	81	0.29
D6	50min	213	164	83	0.28

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The relation between elastic moduli and ultrasonic wave velocities was studied for austenitic stainless steel specimens subjected to various heat treatments. The trend of change in values of young's modulus and shear modulus from S1to S6 is similar to the trend of change in ultrasonic shear wave velocity and this is shown in fig.3. But, the longitudinal velocity changes with almost similar trend with bulk modulus and Poisson's ratio. The correlation studies on longitudinal and shear wave velocities with elastic constants indicates that both longitudinal and shear wave velocity can be used for material characterization. This is similar to the results of our previous work [17].

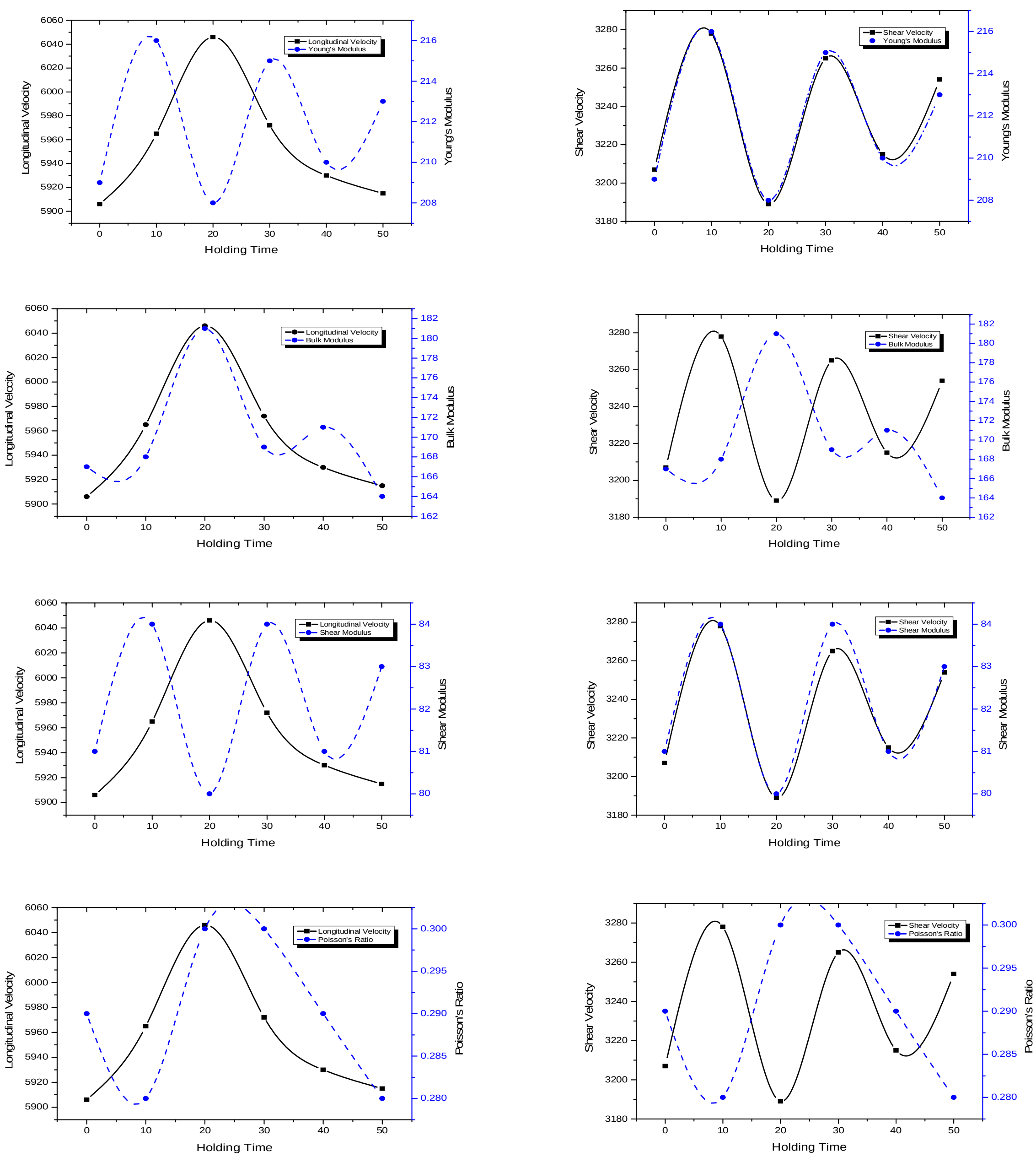

Fig. 3. Correlation between Elastic constants and ultrasonic velocity of AISI 316 Grade Austenitic stainless steel.

IV. CONCLUSION

A systematic approach to understanding the behaviour of sonic velocity in different microstructures obtained by the various heat treatment cycles on the austenitic stainless steel specimens. The correlation studies on ultrasonic velocities with the hardness and with elastic constants have been presented in this work. According to the results obtained one can conclude the following

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The ultrasonic longitudinal velocity was found to decrease from the sample D4 onwards as the grain growth starts to takes place from D4, whereas the ultrasonic shear wave velocity changes in opposite trend with ultrasonic longitudinal velocity.
The correlation studies on ultrasonic velocity with hardness indicates that hardness is mostly dependent on shear wave velocity
For material characterization by ultrasonic technique both longitudinal and shear wave velocity is essential.

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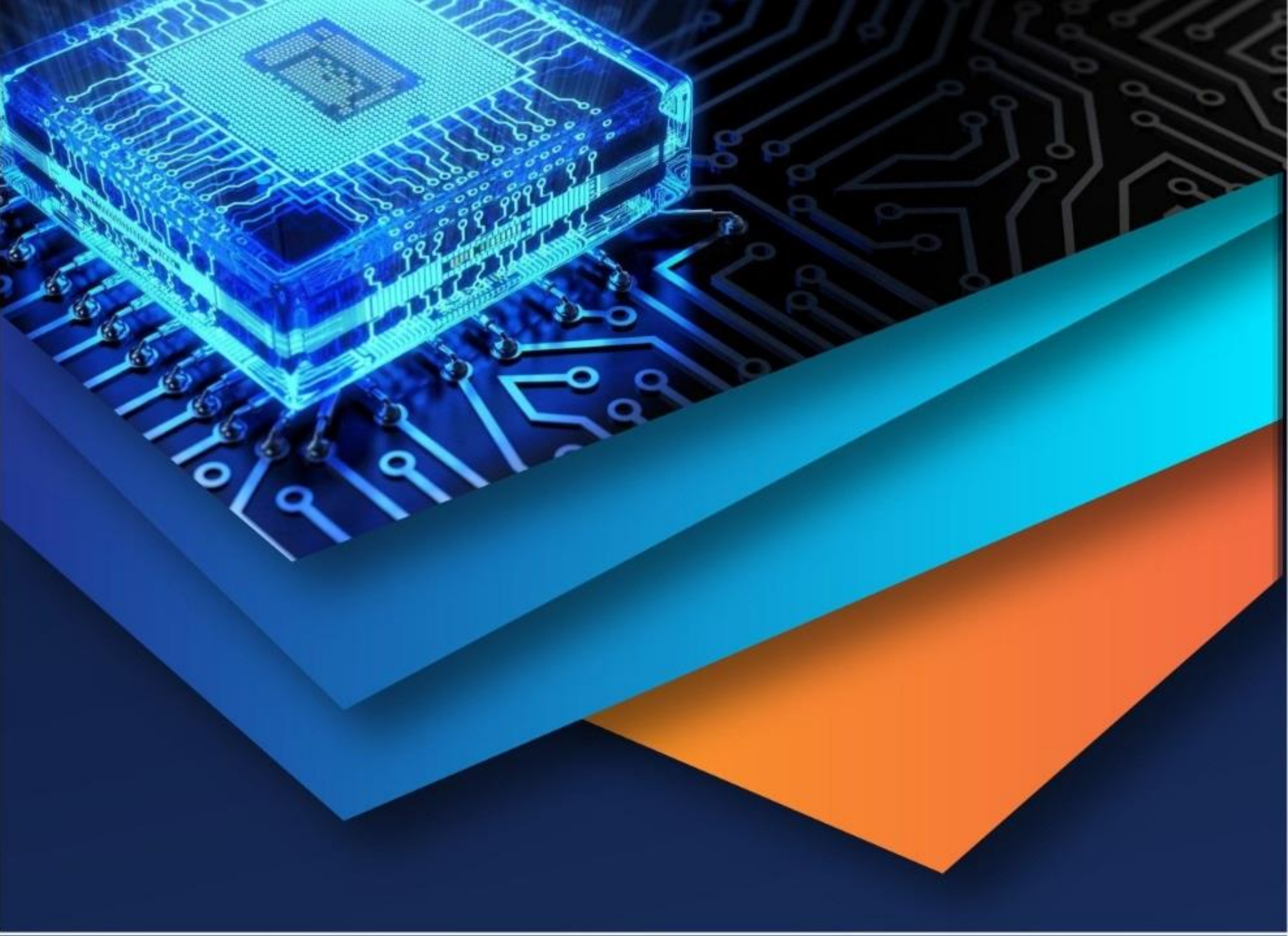

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