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Mechanical Properties Of As Rolled and Tempered 5SP Steel

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Abstract-The effect of tempering temperature and time on the mechanical properties of as – rolled 5SP steel, has been investigated. 12mm ribbed bar samples were taken out of the production batch of 10th June 2007 of the light Section Mill of Ajaokuta Steel Plant. The samples were prepared and quenched in water at room temperature before being tempered at various temperatures between 400 °C and 600 °C and varying lengths of time from 1hr to 3hrs. Results show significant improvement in the yield strength, tensile strength, hardness and impact strength investigated. The tempering temperature-time range for the best yield and tensile strengths were 500 to 600°C and 1 to 1.5hrs while for impact strength, temperatures of 500°C to 600°C and holding time of 2 to 3 hours gave the best results. The gain in yield and tensile strengths of 5SP steel on tempering indicates the viability of an on line thermal treatment during rolling. A chart relating tempering time/temperature and hardness of the steel was established using Hollomon Jaffe tempering parameter.

I. INTRODUCTION

The tendency to easily yield to various fabrication processes and its cost effectiveness has made plain carbon steel a widely used material for industrial application [1]. The major alloying element in plain carbon steel is carbon the amount of which classifies it as low, medium or high carbon steel. Steels with carbon content between 0.25 and 0.65 are classified as medium carbon steel [2]. These steel type balance ductility and strength and has good wear resistance. Apart from the demand of medium carbon steel in the industry as construction materials they are equally used in pieces of machineries such as connecting rods, shafts, springs, brake systems, forgings among others [3; 4]. The peculiar mechanical properties that endeared medium carbon steel to its variety of industrial applications are linked to its microstructure. This structure is made up of small crystals called grains the nature (size, composition and shape) of which determines its mechanical properties. The qualities of medium carbon steel not withstanding; several researchers are constantly seeking ways of improving on these properties through varieties of heat treatments [5-8]. For structural steels, this is occasioned by complex architectural designs desiring steels of improved strength to thickness ratio. Daramola et al [8] investigated the effect of heat treatment on the mechanical properties of rolled medium carbon steel. They austenitized at 830°C, quenched in water. Further, they reheated to 745°C and quenched rapidly in water. Finally, they tempered at 480°C to obtain a strong, tough martensite in a ductile soft ferrite matrix. The steel developed was said to have excellent combination of strength and ductility. Another researcher [7] assessed the mechanical properties of medium carbon steel after quenching in palm oil and water. His result showed that both water and oil quenching produced desirable results. 5SP steel whose carbon content ranges between 0.28 and 0.38 is classified as medium carbon steel. Other alloying elements in 5SP steel are silicon (0.15-0.3%) and manganese (0.5-1.0%). Sulphur and phosphorous content in 5SP steel must not exceed 0.05 and 0.04% respectively. Rolled 5SP steels are products of a mechanical forming process called rolling. Here billets are deformed to shape in rotary rolls cut to sizes, cooled and piled etc [8]. Prior to rolling, steel billets are preheated in a reheating furnace which receives the billets one at a time through roller table. Later, the preheated billets are made to pass through series of stands where reduction is affected [8]. The theory of heat treatment is based on the fact that alloys experience change in structure when heated above a certain temperature and they equally undergo changes in structure when cooled to room temperature. Cooling rate is therefore a factor necessary in realizing the desired properties. It follows then that temperature and time are variables that can be used to study the effects of certain heat treatment processes such as tempering on the properties of steel. Tempering consists of heating hardened steel below its lower critical temperature and cooling the piece in air or through any other desired rate 2. Hardening of steel by quenching usually generates a metastable structure called Martensite [7]. The intention during tempering is to allow diffusion processes to take place leading to martensitic decomposition. It follows that while quenching is accomplished without diffusion, tempering is a diffusion controlled process. Depending on the class of tempering adopted (low, medium or high temperature tempering), different properties are attained. For a given type of steel it is possible to choose convenient time and temperature to achieve respectively the

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same hardness in tempering. Hollomon and Jaffe developed a parameter which relates hardness to tempering temperature and time [1].

$$H = f[T(C + \ln t)] \qquad (1)$$

where

T = tempering temperature

t = tempering time

C = a constant whose value depends on the composition of austenite.

H = Hollomon Jaffe parameter.

This work aims at investigating how 5SP steel responds to tempering heat treatment with a view to assessing the viability of a thermo mechanical on-line treatment during rolling in Ajaokuta steel plant, Nigeria. It also aims at improving the mechanical properties of articles manufactured with such steel in the fabrication shops of the company. The Minimum yield strength for marketable as rolled 5SP steels is 420N/mm^2. The higher this is the more acceptable the products are.

II. MATERIALS

Test materials were collected from the Research and Quality Assurance Department of Ajaokuta Steel Company Limited. Samples were taken from a 12mm ribbed bar drawn from the production batch of 10th June, 2007. The chemical composition of the selected 5SP steel was determined using a ferrous metal spectra analyzer installed in the foundry shop of Ajaokuta Steel Company. The well-polished sample was clamped properly at the mounting, ensuring no space between the sample and electrode before the electrode was sparked.

The spark excited the atoms of the different element which emitted characteristic line of different intensities. Attached software analyzes the intensity of the spectrum and presents quantitative information of the sample on the screen. The chemical composition of the steel material obtained was as shown in Table 1.

Table 1: Chemical composition of As- Rolled 12mm 5SP Steel

Element	Wt%	Element	Wt%
C	0.332	Cu	0.183
Si	0.289	Nb	0.006
Mn	0.989	Ti	0.004
P	0.039	V	0.006
S	0.048	N	0.011
Cr	0.073	Pb	0.005
Mn	0.005	Sn	0.026
Ni	0.100	Zn	0.008
As	0.028	Fe	97.81
Co	0.016		

III. TEST PROCEDURES

Since 5SP Steels are hypoeutectoid steels, the relevant critical temperature is $AC_{3,}$

Using the Grange empirical formula [8],

$$AC_3\,(^oC) = \{1570 - (323C - 25Mn + 80Si - 3Cr - 32Ni - 32)\} \times 5/9 \qquad (2)$$

Inserting values from table 1 we have

$$AC_3\,(^oC) = 797.66^\circ C \approx 800^oC \qquad (3)$$

According to Singh [9], austenitizing temperature for result oriented quenching is given by the formula:

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$$A_T = AC_3 + (20^oC \text{ to } 40^oC) \qquad (4)$$

Inserting the value of AC_3 for (3) we have

$$A_T = 820^oC \text{ to } 840^oC)$$

Hence an austenitizing temperature of 830 was adopted.

The soaking time adopted was 10 minutes. This was guided by the experientially determined total heating time for electrically heated furnace which is put at 40 to 50 seconds per mm of work piece diameter.

The effect of tempering temperature was first studied by heating the quenched samples to temperatures between 400^{o}C and 650^{o}C. A constant soaking time of 60 minutes was observed for all the samples after which the samples were cooled in air.

To determine the effect of tempering time, a constant tempering temperature of 500^{o}C was used. Time variation was between 1 to 3hrs. Tempered samples were subjected to tensile, impact and hardness tests.

IV. RESULTS AND DISCUSSIONS

A. Results

Fig.1 shows the mechanical properties of as – rolled 5SP Steel compared with its properties after quenching.

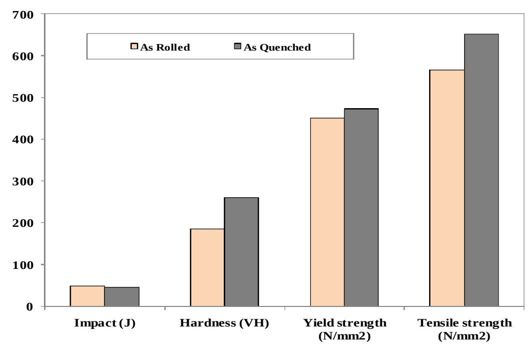

Fig. 1: Mechanical properties of as rolled 5SP steel compared with properties after quenching in water from austenitic temperature

It can be observed that apart form the impact energy of the as quenched sample that is slightly lower than that of the as rolled sample, all other mechanical properties studied were higher in the quenched specimen than the as rolled specimen. While Fig. 2 shows the effect of tempering temperature on the Impact Strength and hardness of 5SP Steel Fig. 3 shows the same effect on yield strength and tensile strength all at holding time of 60 minutes. At all temperatures considered, the impact energy decreased with temperature while the hardness increased with temperature. On the other hand, both the yield strength and tensile strength increased with increase in temperature.

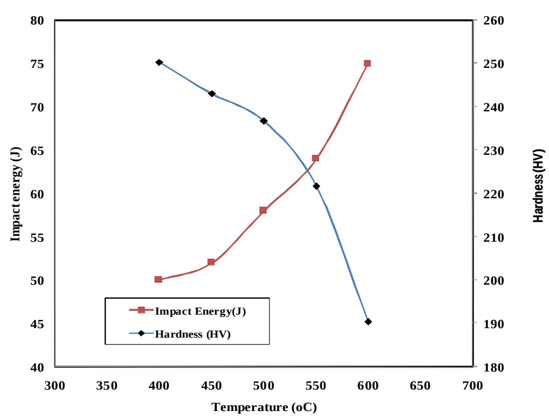

Fig. 2: Effect of Tempering Temperature on the hardness (HV) and impact energy (J) of 5SP steel at a Holding Time of 60 Minutes

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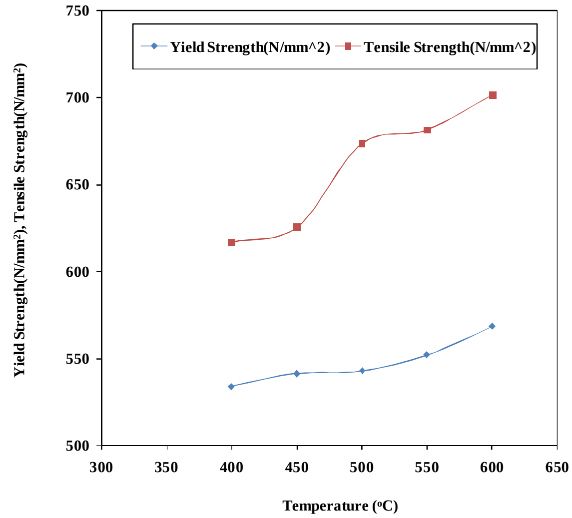

Fig. 3: Effect of Tempering Temperature on the mechanical properties of 5SP steel at a holding Time of 60 Minutes

Fig. 4 shows the effect of tempering time on the impact strength and hardness at a constant temperature of 500°C. The hardness decreased while the impact strength increases with tempering time. The variation of yield and tensile strengths with tempering time and at the same temperature is shown in fig 5. Both decreased with increase in tempering time.

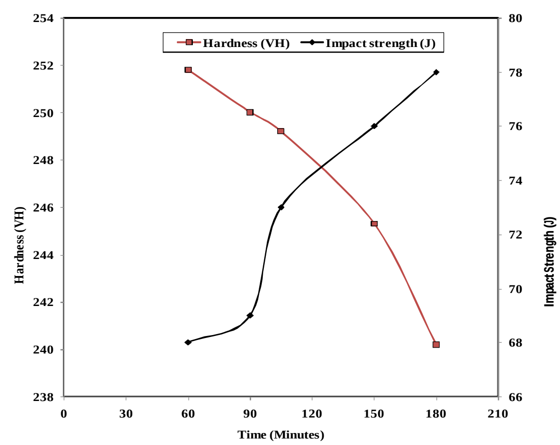

Fig. 4: Effect of tempering time on the impact strength and hardness of 5SP steel tempered at 500ºC.

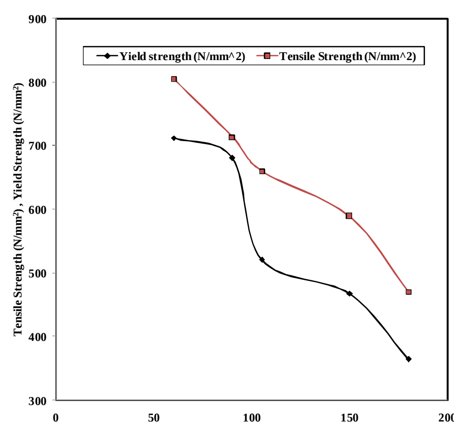

Fig. 5: Effect of tempering time on the Yield strength and Tensile Strength of 5SP steel tempered at 500ºC.

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Relationship between hardness, temperature and tempering time obtained from Holloman Jaffe parameter, HP = T (C + Logt), with the value of C taken as 18 is shown in Fig. 6

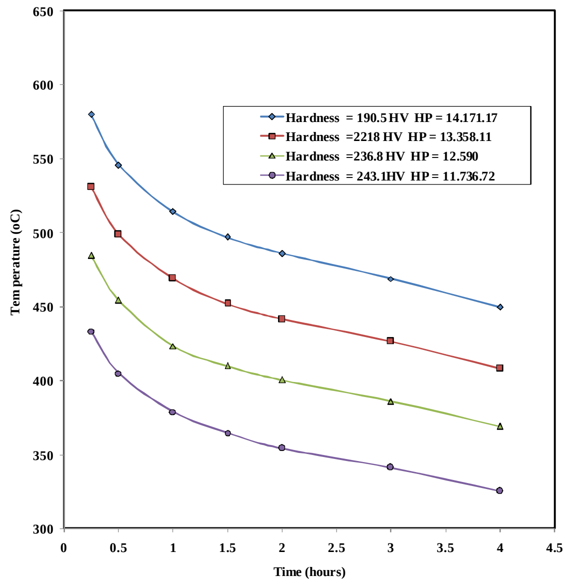

Fig. 6: Time, Temperature and Hardness relationship in Tempering of 5SP Steel (Use of Hollomon Jaffe Tempering Parameter)

B. Discussion of Results

The obvious gain in hardness observed when the as rolled and quenched properties of 5SP steel were compared (Fig. 1) can be attributed to formation of martensite. The formed martensite increased the brittleness of the sample and hence caused a reduction in the impact energy. The gain in tensile strength of the as quenched sample was probably due to realignment of imperfections such as dislocations. As expected the hardness of tempered 5SP steel increased as the tempering temperature was decreased, Fig. 2. At the early stages of tempering, the tetragonality of martensite tends to decrease. This naturally should lead to a decrease in the hardness of the steel in question. However at these stages too, precipitation of epsilon carbide also occurs. These precipitates increase the hardness of steel. The net effect in this case was a decrease in hardness which implies that the former phenomenon was stronger. In high carbon steels (about 1.2%C) a slight increase in hardness was even detected at this range [9], because of higher epsilon carbide precipitation than softening caused by reduction in carbon tetragonality. At higher stage of tempering, the decrease in hardness, is attributable to the dissolution of the ε -carbide in the matrix and the complete loss of tetragonality of martensite. A further decrease in hardness could also be due to growth in size and decrease in the number of cementite particles as temperature rises further close to A_1. The hardness of 5SP steel samples tempered at 500 ºC decreased with increase in tempering time, Fig. 4. Diffusion process which is time dependent could be a factor in this instance. The longer the material was tempered, the higher the time available for the dissolution of ε -carbide and growth in size of any precipitated cementite particles. Fig. 3, shows the relationship between Yield strength, Tensile Strength and Tempering Temperature. As temperature rises between 400^oC and 700^oC, there is a reduction of ferrite – cementite interfacial energy which leads to spheroidization. Also annealing out of lattice defects takes place with substantial recovery occurring as well. All these would lead to a more stable structure. This probably explains why the yield and tensile strengths increased with increase in tempering temperature. Yield strength is the principal index of the strength of metals and is essential in static loading designs to determine allowable stresses. The higher the value of a yield strength and consequently tensile strength, the less the cross section and mass of material required to withstand certain stress conditions. In Fig. 5, tensile strength and yield strength are seen to decrease with increasing tempering time. This may be attributed to grain coarsening and growth as a result of increased dwell time at the tempering temperature. The impact strength of the heat treated 5SP steel samples increased as the tempering temperature as well as time was increased, (Fig. 2, 4). This took place at the expense of hardness and is probably due to the fact that at higher temperatures and longer time, carbon was able to precipitate into tiny carbide particles. At such temperatures and time, structural steels having carbon content of 0.3 - 0.5 % usually develop sorbtitic structure, having been relieved of virtually all residual stresses.

Daramola et al [8], in their work found that after quenching, lamelarising and tempering, the toughness of medium carbon steel as

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well as its tensile strength increased.

The relationship between hardness, temperature and time of heat treatment of samples of the 5SP steel is shown in Fig. 6. This was derived using Hollomon and Jaffe tempering parameter. The chart presents a reasonable guide to heat treaters for 5SP steel. It is possible for a heat treater to know, using this chart at what temperatures and time to achieve certain hardness. It is thus a useful tool for heat treating articles manufactured with the class of steel in question. Furthermore, such charts can be prepared using experimental results for other classes of steels. Gil et al [10] got similar result, when they investigated the influence of tempering temperature and time on the properties of αTi-6Al-4V martensite.

V. SUMMARY OF FINDINGS AND CONCLUSIONS

That medium carbon steels respond to heat treatment in various ways is already an established fact. The main focus of this research was therefore to zero in on 5SP steel, a type of medium carbon steel often used for manufacturing processes in Ajaokuta Steel Company, to asses to what extent such steel respond to tempering heat treatment. This was with a view to establishing guiding data and information to enhance the production of more qualitative engineering material and spare parts components while using 5SP steel as the starting stock. In producing reinforcement bars in the rolling mills, higher yield strength is considered an advantage over other competitors. This is because the designers would prefer such material which would ultimately lead to project cost reduction and of course a more enduring structure. The idea to install an on-line process called “thermo mechanical treatment” in the Light Section Mill (L S M) of Ajaokuta Steel Plant had thus been contemplated.
Furthermore engineering articles manufactured with these steel in the Company’s workshops constantly face higher quality demands from user departments. This research work which examined the effect of tempering temperature and time on the mechanical properties of 5SP steel came up with useful findings. Quenching heat treatment on the 5SP steel used resulted in a significant increase in the profiles’ yield and tensile strengths within tolerable hardness values. This essentially was the aim of the “thermo mechanical treatment” proposed at the Light Section Mill of Ajaokuta Steel Plant. Considering the results of this work, it could therefore be concluded that installing such a process would be a worthwhile venture.

Tempering heat treatment at various temperatures and times produced significant effect on the mechanical properties of the steel. The temperature-time range for the best yield and tensile strengths were 500 ºC to 600 ºC and 1 to 1.5hours respectively for the temperature-time range considered. For impact strength temperatures of 500 ºC to 600 ºC and holding time of 2 to 3hours gave the best result. From the foregoing, it could be concluded that the optimum strength properties of the steel samples is attained when tempered between 500 to 600^{o}C for a time of 1hr. to 1.5hrs.

Using Hollomon and Jaffe tempering parameter, a chart for tempering temperature and time with hardness was established. The chart could be useful while conducting tempering heat treatment on 5SP steel articles.

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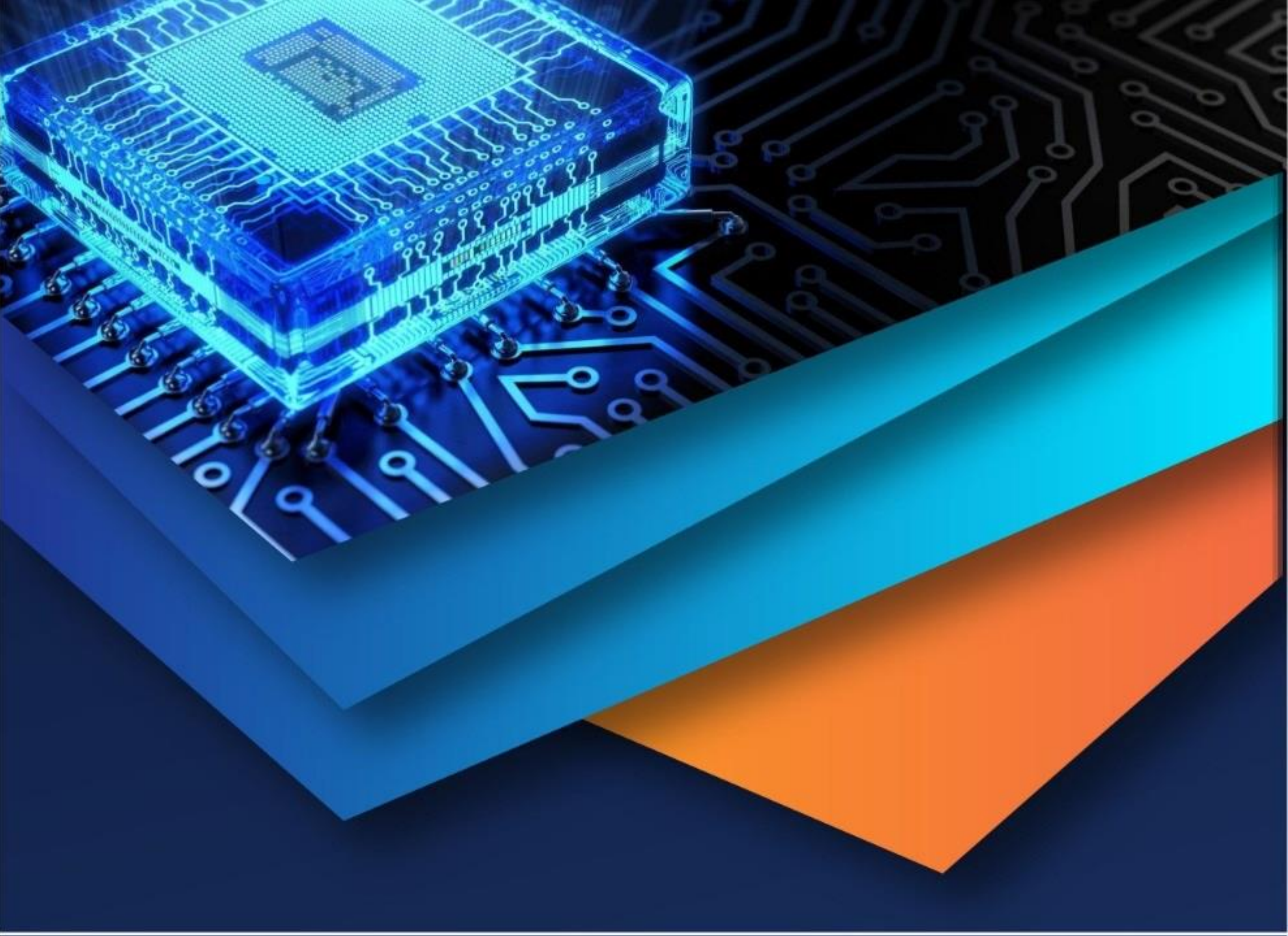

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