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To study the Effect of Organophilic Nano-clay on Creep Stiffness of Asphalt Binder at Low Temperatures

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Abstract: The asphalt binder must be modified to extend the service life of flexible pavements. As the temperature outside drops, the pavements shrink and develop internal stresses. The pavement may break if this contraction happens quickly enough because it won't have time to relax these stresses. Due to the cracking's orientation with respect to the flow of traffic, this form of fracture is frequently referred to as a "thermal crack" or a "transverse crack.". The purpose of this article is to assess how adding nanoclay to asphalt binder changes its performance at low temperatures. The stiffness and stress relaxation time of a material can be measured with a Bending Beam Rheometer (BBR). It is ideal for asphalt binders to be able to release built-up tensions and not become overly stiff at low temperatures. The BBR test was carried out to investigate the low-temperature behaviour of asphalt binder. Test samples were prepared by adding varying nanoclay content and test temperatures were defined. Three small beams of each percentage were prepared and tested after conditioning at defined test temperatures. Results of modified asphalt binder were assessed and contrasted to unmodified asphalt binder to optimize the nanoclay content. The study revealed that increment in nanoclay amount increased the creep stiffness of asphalt binder. İt was concluded from the study that improvement of creep stiffness played a key role towards the low-temperature performance. The maximum increase in creep stiffness was found by the addition of 5 % nanoclay at -16 °C.
Keywords: Creep Stiffness, Organophilic Nanoclay, Asphalt Binder, Bending Beam Rheometer (BBR), Low-temperature Performance.

I. INTRODUCTION

Low-temperature asphalt binder stiffness and relaxation properties are measured using the Bending Beam Rheometer (BBR) test. The bituminous layers may crack if the binder is low-temperature sensitive. The flexural creep stiffness of the low-temperature mastic does not seem to be affected by the chemical make-up or shape of the filler, according to research of the effectiveness of bituminous mastic under freezing conditions [1]. We can draw the conclusion that, with a slower loading rate, the BBR strength test has been utilised to determine the rheological characteristics of asphalt binders. This method is greatly easing the assessment of low-temperature cracking resistance by allowing us to acquire both rheological and strength parameters from a single BBR strength test [2]. Asphalt pavements commonly fail due to low-temperature thermal cracking, especially in regions with considerable temperature variations. The effectiveness of asphalt pavements in cold weather can be managed by adjusting the low-temperature rheology of the asphalt binders. Asphalt binders are tested using the BBR at low temperatures to see how susceptible they are to thermal cracking [3]. At all temperatures, nano-montmorillonite k10 reduces creep stiffness and raises the m-value, indicating that it enhances cold weather performance. Adding Sasobit and nano-montmorillonite k10 to bitumen at the same time improves its low-temperature characteristics. The 8 rheological characteristics of pure bitumen were improved by nano clay [4]. The BBR test is used by the Superpave™ specification to assess the low-temperature functionality of an asphalt binder. The test assesses the binder's potential resistance to thermal cracking and stress relaxation in samples of asphalt bending beams. Chemical alterations and physical treatment techniques can help asphalt binder's low-temperature anti-cracking characteristics to some extent [5]. According to creep stiffness and m-value rheological parameters, the low-temperature performance of asphalt binder could be negatively impacted by dosages of more than 2% SNS. The asphalt concrete cracking instrument, the semi-circular bending test, and the indirect tensile tests are used to gauge the low-temperature characteristics of asphalt mixtures treated with nanoclay [6]. The outcomes show that after the application of nano clay cracking and rutting, particularly fatigue resistance is improved at 4 percent (by weight of asphalt binder). At low temperatures, the S and m-values show that modified asphalt binder outperforms the control asphalt binder. The fatigue properties of modified asphalt binder are improved by nano clay addition, delaying the onset of early fatigue fractures in mixtures containing modified asphalt binder [7].

Nano clay surpasses Nano alumina in terms of improving the binder's resistance to rutting. The ability of the binder to relax tensions decreased as the amount of Nano clay in the mixture increased, increasing heat stresses instead. Because Nano clay was added, the failure strain percentage decreased, making it more prone to cracking at low temperature. Asphalts with nano clay modifications are being used more and more to reduce low-temperature cracking [8]. Conclusion: The inclusion of nanoclay increases the chances of cracking due to cold weather and provides reinforcement for the tensile strength qualities of the asphalt binder. Conclusion: Unmodified asphalt outperformed nano clay-modified asphalt mixtures when temperatures were low (5°C). It has been demonstrated that asphalt bitumen treated with nano clay has improved anti-aging and anti-deformability capabilities at low temperatures [9]. The effectiveness of bituminous nanoclays for use in road paving at low temperatures is the main topic of this research. Using the S and m parameters together for blends including basic bitumen B1, we can conclude that, for CNTs, improved cold weather performance was consistently achieved with the use of a lower modification dose [10]. When compared to two other popular asphalt binders—5% SBS modified asphalt binder and AH-70 base asphalt binder—the modified asphalt binder we recommend far outperforms them. At low temperatures, as shown by the asphalt binder's smaller S values and higher m values, it is challenging to gather stress and break [11]. Nanoclay Low performance-graded (PG) asphalt binders with lighter constituents had favourable low-temperature anti-cracking characteristics. The creep stiffness was reduced in part using fine nanoclay. The mixing temperature, time, and rate had an impact on the low temperature properties, so the production parameters needed to be carefully chosen [12]. In northern areas of Pakistan, temperature drops below -15 °C and due to this temperature drop phenomenon of creep stiffness occurs in such areas. To increase resistivity of asphaltic material against this phenomenon of creep stiffness studies have been conducted by adding different types of admixtures. In this study, we will perform comparative Bending Beam Rheometer (BBR) tests on unmodified and nanoclay modified bitumen samples. Nanoclay is used as an additive to enhance the healing capability of hot mix asphalt (HMA).

II. PROBLEM STATEMENT

Bitumen is a visco-elastic material and its behaviour changes under different temperature and loading condition. Low temperatures cause asphalt pavement to become stiff and brittle, which leads to earlier cracking and a shorter service life. Due to the binder's weak low temperature resistance to heavy traffic volume, cracks emerge. High binder cost raises the pavement cost per kilometre. The study's goal is to determine how adding Organophilic nano clay to asphalt modifies its properties at low temperatures and what concentration of nano clay is best for providing resistance to cracking at those temperatures.

III. AIMS & OBJECTIVE

The following are the study's primary goals:

1) To Characterize the asphalt binder with and without modifier.
2) To study the effect of Organophilic Nano clay on low-Temperature performance of Bitumen.
3) To Optimize Percentage of Organophilic Nano clay in Bitumen.

IV. MATERIALS

A. Asphalt Binder

The National Refinery Limited in Karachi provided the NRL 60/70 asphalt binder that was employed in the study. The basic physical properties of asphalt binder were measured in accordance with ASTM standards and recorded in Table 1.

TABLE I
Physical Properties of Asphalt Binder

Properties	Standard Code	Unit	NRL 60/70	Specification Limit(minimum)
Penetration 0.1 mm @25°	ASTM D5	1/10 mm	60-70	60
Softening Point (°C)	ASTM D36	°C	46-57	43
Ductility at 25°C	ASTM 36	cm	100	100
Dynamic Viscosity	ASTM D4402	cP	340.2	300

Figure 1: Asphalt Binder NRL 60/70

B. *Nano Materials (Modifier)*

Nano material used in this study is organophilic nanoclay, shown in figure 2.

Figure 2: Organophilic Nanoclay material

An important organic-inorganic hybrid known as "organophilic nanoclay" is created by cleverly combining two different components, namely clays and organic molecules, at the molecular and nanoscale levels. This hybrid's clay component offers a 2-D layered structure with intriguing surface chemistry that can be modified by organic molecules. The schematic diagram of organophilic nanoclay is shown below:

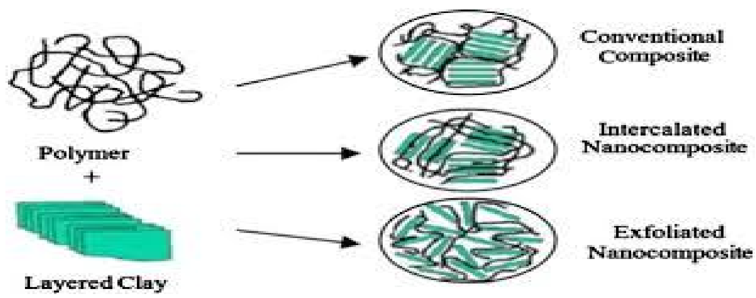

Figure 3: Schematic of structure of polymers of nanocomposites (Golestani et al. 2012)

V. METHODOLOGY

Using 60/70 NRL (National Refinery Limited) asphalt binder, three samples for each nanoclay content (3%, 3.5%, 4%, 4.5%, 5%) were prepared to conduct the bending beam rheometer test in accordance with ASTM D-6648 ("Standard Test Method for Determining the Flexural Creep Stiffness of Asphalt Binder using the Bending Beam Rheometer") standard.

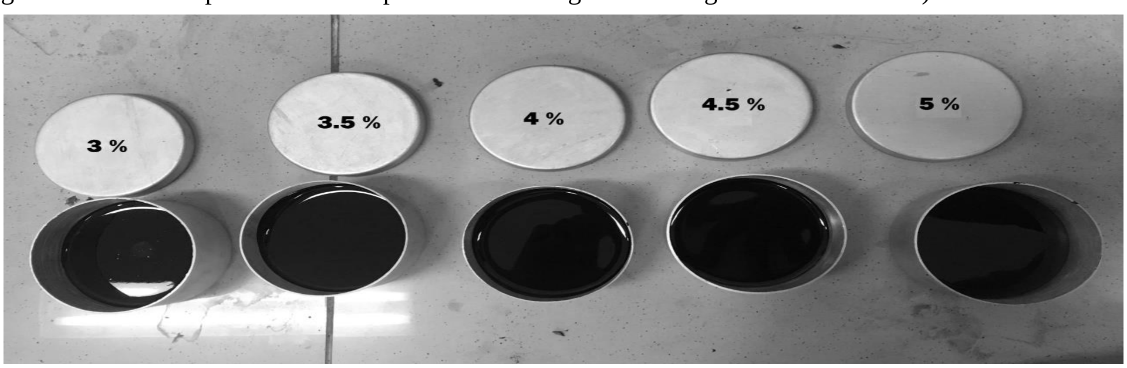

Figure 4: Nanoclay modified asphalt binder with different percentages

A. *Bending Beam Rheometer Test*

In the experimental study, we used Bitumen of 60/70 penetration grade sourced from National refinery Limited Karachi. Nanoclay was used as a modifier to compare the creep stiffness of modified and neat bitumen performing the Bending Beam Rheometer (BBR) test. After sourcing the material, samples for Bending Beam Rheometer (BBR) test were prepared using aluminum moulds. Beams of 127 $\pm$ 5 mm length, 6.35 $\pm$ 0.05 mm width, and 12.70 $\pm$ 0.05 mm depth were prepared and conditioned at the required temperature. Nanoclay was added in different proportions to study the creep stiffness behavior of the asphalt binder.

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After preparing samples, the required temperature was achieved, and necessary calibrations were done on the BBR machine. After that, we placed the sample beams in the loading frame and run the computer program to get the readings of creep stiffness at different temperatures and different proportions of the modifier added. This test was conducted at different low temperatures i.e., 2 °C, -4 °C, -10 °C, and -16 °C.

This BBR test uses a simple procedure of placing the sample asphalt beam on a simply supported setup which is emersed in a cold liquid bath to maintain the required test temperature. Then a point load is applied at the middle of the beam and deflection against time period is found. This deflection and properties of the beam collectively give the measure of stiffness. How well the asphalt binders relax the loads is measured by the stresses that are created.

The stiffness measured is calculated by the formula given:

$$S(t) = \frac{PL^3}{4bh^3\delta(t)} \quad (1)$$

where:

S (t) = flexural creep stiffness at time t, MPa,

P = measured test load, mN,

L = distance between supports, mm,

b = width of the test specimen, mm,

h = depth of test specimen, mm, and

$\delta(t)$ = deflection of the test specimen at time t.

Figure 5 : Bending Beam Rheometer (BBR)

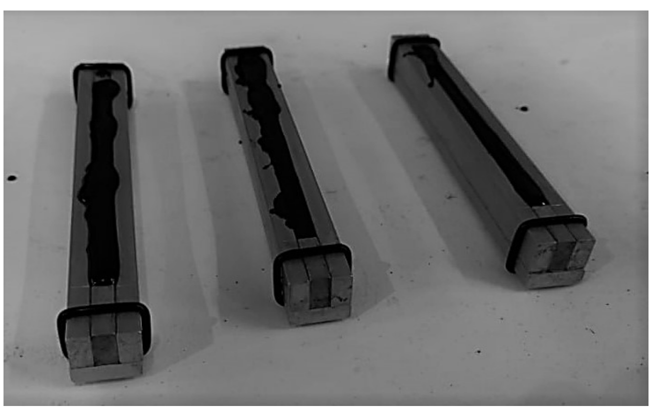

Figure 6 : Bending Beam Rheometer (BBR) Test Samples

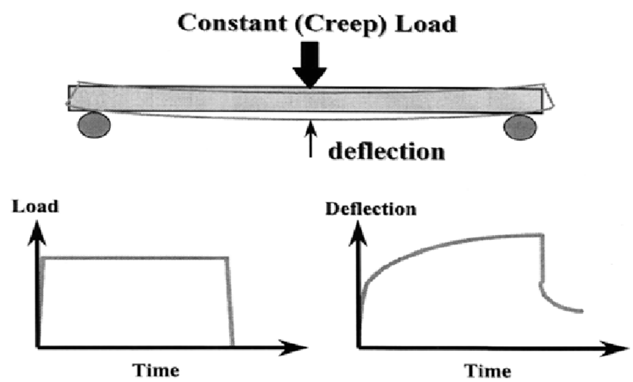

Figure 7 : BBR Test Principles (Geoff Rowe et al. 2000)

VI. RESULTS & DISCUSSIONS

A. Impact On Creep Stiffness

To better understand how the strength of the asphalt binder changed in response to low-temperature cracking, nanoclay was added to it in percentages of 3, 3.5, 4, 4.5, and 5. Tests were conducted at four different temperatures to study the change in performance grade temperature ranges with the addition of nanoclay as a modifier.

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The study revealed that with the increase in nanoclay (modifier) content the stiffness of the asphalt binder went on increasing. İn figures (8,9,10,11,12 & 13) the results show the increase in stiffness with the increase in nanoclay content at four different temperatures. The increase in stiffness shows that the strength of the asphalt binder against low-temperature cracking increases with the increase in nanoclay content added to the asphalt binder as a modifier. The results showed that the maximum The stiffness increased as a result of the addition of 5 % nanoclay at -16 °C. İt means that with the decrease in temperature the stiffness also increases.

TABLE III
Impact Of Organophilic Nanoclay On Creep Stiffness Of Bitumen

Stiffness at different temperatures vs NC%				
NC %	2°C	-4°C	-10°C	-16°C
0	40.15	98.23	139.62	234.54
3	135.31	175.51	268.14	322.61
3.5	195.28	218.02	298.91	378.12
4	231.76	269.27	354.16	422.81
4.5	251.04	295.22	385.91	458.91
5	294.12	352.17	422.16	495.65

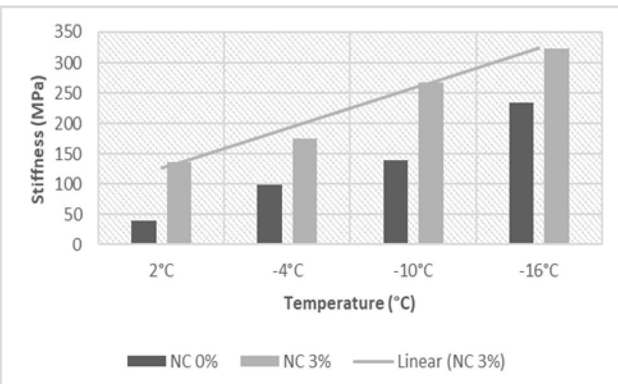

Figure8: Stiffness of neat binder and modified with 3 % nanoclay

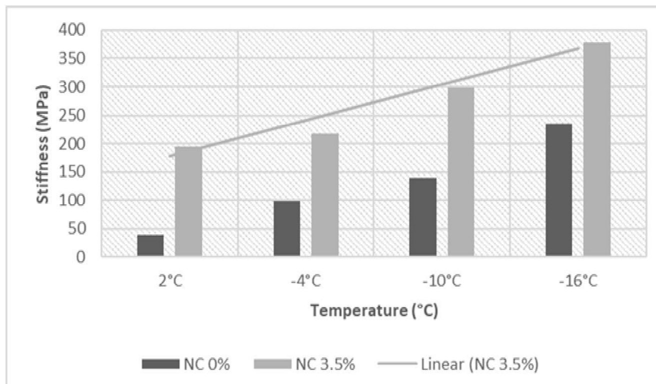

Figure9: Stiffness of neat binder and modified with 3.5 % nanoclay

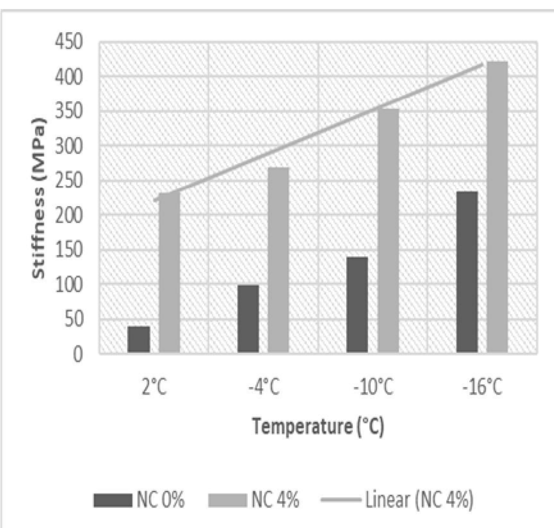

Figure10: Stiffness of neat binder and modified with 4 % nanoclay

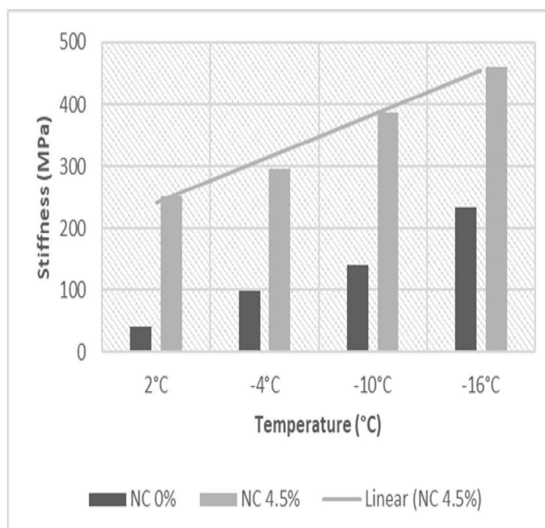

Figure11: Stiffness of neat binder and modified with 4.5 % nanoclay

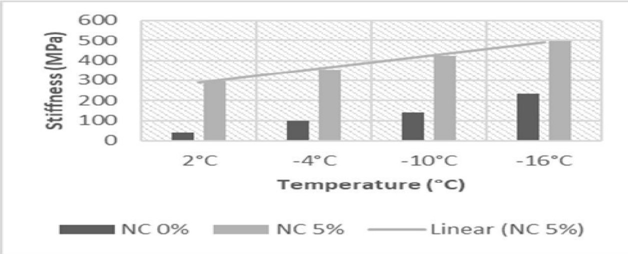

Figure12: Stiffness of neat binder and modified with 5 % nanoclay

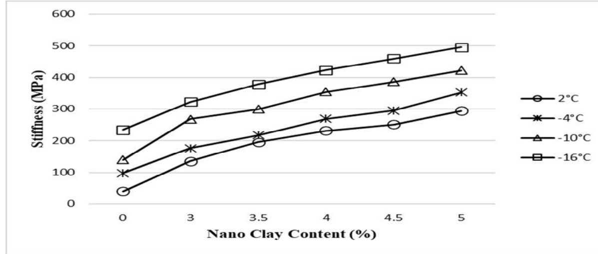

Figure13: Effect of nanoclay content at different temperatures

Figure 13 shows, after performing the tests the stiffness of nanoclay modified binder increased with the increase in nanoclay content. It shows the comparison of virgin and modified binder creep stiffness at four different lower temperatures.

VII. CONCLUSIONS AND RECOMMENDATIONS

After comparison of BBR results of neat and modified binder with (3%, 3.5%, 4%, 4.5%, and 5%) following conclusions and recommendations were drawn out:

1) 1) In this investigation, bending beam rheometers at low temperatures were used to assess the stiffness properties of the asphalt binder. After nanoclay was added as a modifier, the stiffness property of the asphalt binder was improved.
2) The creep stiffness of asphalt binders associated with the low-temperature cracking is improved with the addition of organophilic nanoclay. As the amount of nanoclay introduced (as modifier) in asphalt binder increases the amount of flexural creep stiffness increases. Flexural creep stiffness is property of the asphalt binder to take flexural stresses and to relax the asphalt material after the removal of stresses to resist the creep failure at low temperatures. Therefore, the increasing trend of flexural creep stiffness has been witnessed after incorporation of nanoclay content.
3) Nanoclay is added in five proportions i.e., 3%, 3.5%, 4%, 4.5%, and 5%. The tes is conducted on four different temperatures i.e., 2 °C, -4 °C, -10 °C, and -16 °C. The values of flexural creep stiffness were found maximum at -16 °C and 5% nanoclay content. It concludes that the maximum effect of nanoclay content occurs at the maximum nanoclay content being added at lower temperatures.

VIII. ACKNOWLEDGMENT

The author appreciates the research-friendly environment offered by all the laboratory workers and the Taxila Institute of Transportation Engineering department, and he will ever remember the immense and extraordinary supervision given by Prof. Dr. Imran Hafeez.

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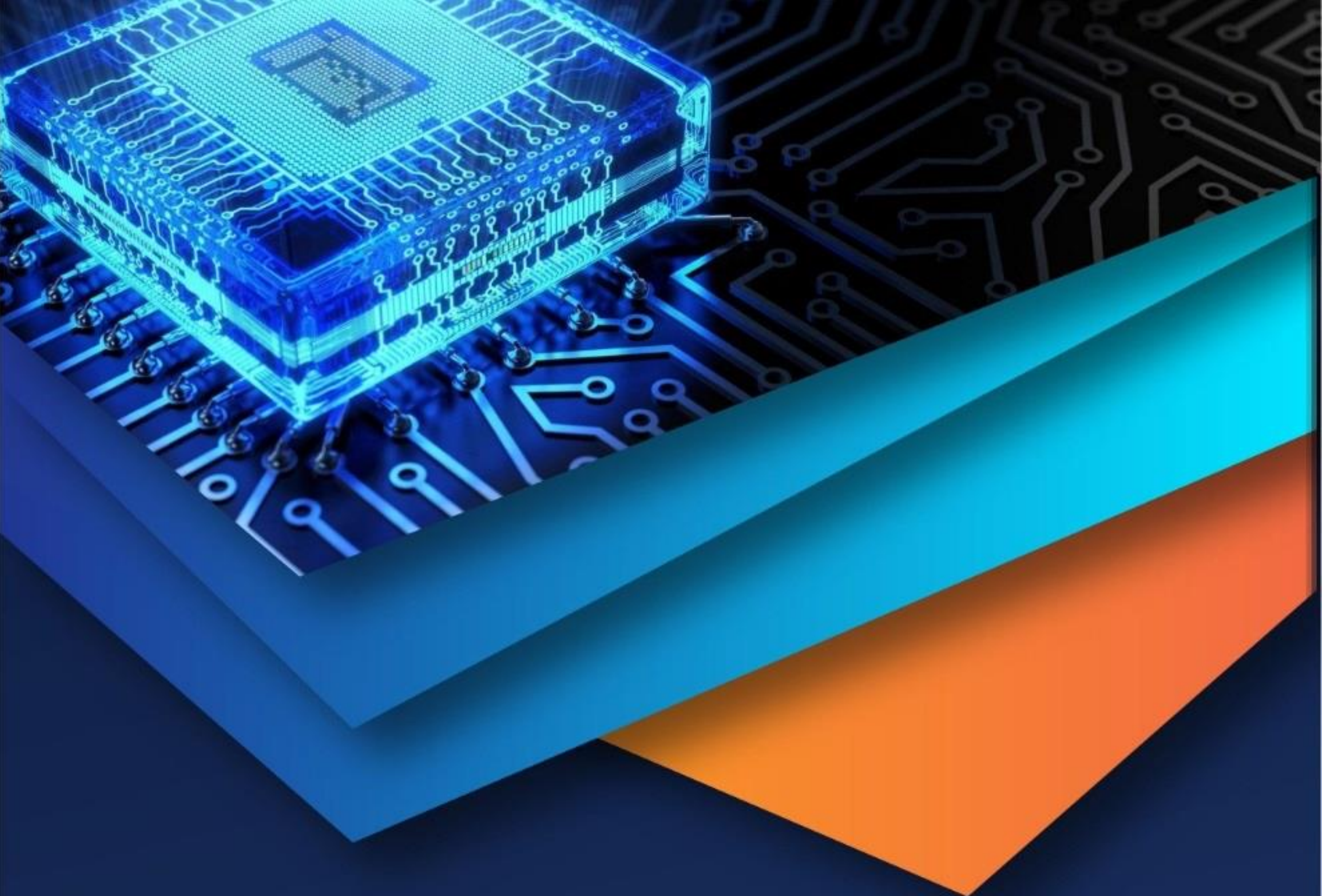

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