Semarak Engineering Journal

Journal homepage:
https://semarakilmu.my/index.php/sej/index
ISSN: 3036-0145

Investigation of the Electrical Properties of AA5052–TiO_2 Composite

Taqwa M. Abdulrahman[1,*], Suad H.A.Raubye[1], Ahmed H. Reja[1]

[1] Al-Nahrain University, Engineering College, Baghdad, Iraq

ARTICLE INFO

Article history:
Received 20 November 2025
Received in revised form 29 December 2025
Accepted 10 February 2026
Available online 15 March 2026

Keywords:

AA5052, Aluminum matrix , electrical conductivity, skin effect, Tio_2

ABSTRACT

This work aims to study the role of $\mathrm{Tio_2}$ nanoparticles added by stir casting to make AA5052/ $\mathrm{Tio_2}$ at concentrations of 0%, 3% and 5%, observing their effect on electrical conductivity and skin effect phenomenon. It was revealed that the AA5052-Tio_2 composites were prepared successfully which was demonstrated using SEM micrographs. The Tio_2 added to the matrix is considered very pure at 99.9%. The phenomenon of the skin effect appeared on the aluminum matrix, which changes with each added amount of Tio_2, and its occurrence decreases depending on the increase in the amount of frequency. Also, Electrical conductivity results were also obtained for samples of aluminum AA5052, as at each specific concentration ratio of titanium dioxide, the electrical conductivity varied, as the results indicate that the frequency is directly proportional to the conductivity for all samples subject for testing. The three samples were compared with each other, and the highest electrical conductivity was observed in sample AA5052 + 3%Tio_2 at frequency 5MHz, reaching about 35.9583. Electrical studies also reported evidence of an improvement in vehicles in comparison with the basic matrix.

1. Introduction

Aluminum is an easily available metal. Its matrix is characterized by the ability to be installed with supportive reinforcements that make its resistance to corrosion better and improve its various properties [1]. In certain cases, any composite matrix, whether made of aluminum or another metallic material, is formed by stir casting with the aim of making improved additions to the base metal [2]. Metal matrix composites (MMCs) offer enhanced properties such as good electrical conductivity, hardness, and wear resistance compared to monolithic metals [17-20]. These composites combine a metal matrix with reinforcing materials like graphene nanoplatelets or carbon nanotubes to improve various characteristics. For instance, MMCs can achieve a balance of properties by incorporating ceramic reinforcements, allowing for strengthened materials without compromising other properties [3,21,22]. The use of nanocomposites, with constituents on the nanometer scale, further enhances material properties, making them different from bulk materials. Overall, composite metal matrix materials are gaining popularity in engineering due to their ability

* *Corresponding author.*
E-mail address: mazin.y.abdulkareem@nahrainuniv.edu.iq

https://doi.org/10.37934/sej.13.1.110

to provide weight-efficient structural solutions with superior electrical properties and a range of other desirable characteristics [4,23-26].

The phenomenon of the skin effect is one of the important electrical phenomena that occurs in conductive metals, specifically in the course of alternating current, where the direct current moves from its normal internal path of the metal or wire and is transmitted in the outer layers of it, as shown in the Figure 1**.**

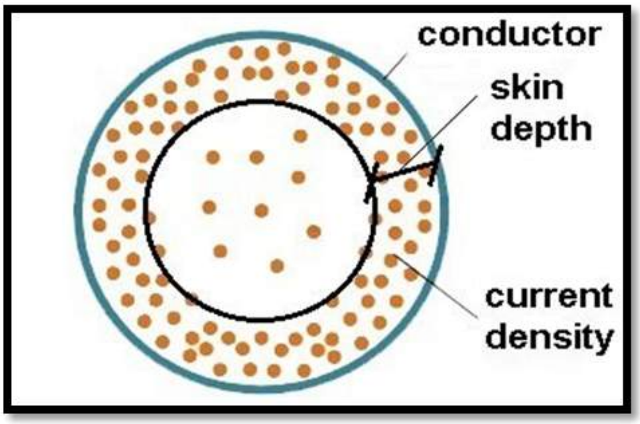


Fig. 1. Skin effect visualization

The mechanism is that if the frequency is low and primitive, meaning low, skin effect rates will be low or may not occur, but when the frequency in alternating current rises to 50 Hz, for example, the skin depth will be at its highest, and as the frequency rises to MHz and above, the skin depth decreases progressively with increasing frequency [5].

Table 1 illustrates skin depth values that appear differently from one conductor to another according to the conditions under which it is measured, such as temperature, relative permeability, or conductivity. If the relative permeability value is large, meaning greater than 1, this reduces the skin depth value, as in nickel and iron metal, which are used in a variety of industrial and applied applications.

Table 1
Skin depth values for various conductors, [14]

Parameters	Silver	Copper	Gold	Aluminum	Nickel	Iron	Stainless Steel 316
σ [S/m]	6,20E+07	5,82E+07	4,50E+07	3,80E+07	1,40E+07	1,00E+07	1,36E+06
μ_r [1]	1	1	1	1	100	1000	1
Frequency	Skin depth [mm]						
10 Hz	20,213	20,862	23,725	25,818	4,254	1,592	136,474
100 Hz	6,392	6,597	7,503	8,164	1,345	0,503	43,157
1 kHz	2,021	2,086	2,373	2,582	0,425	0,159	13,647
10 kHz	0,639	0,660	0,750	0,816	0,135	0,050	4,316
100 kHz	0,202	0,209	0,237	0,258	0,043	0,016	1,365
1 MHz	0,064	0,066	0,075	0,082	0,013	0,005	0,432
10 MHz	0,020	0,021	0,024	0,026	0,004	0,002	0,136
100 MHz	0,006	0,007	0,008	0,008	0,001	0,001	0,043
1 GHz	0,0020	0,0021	0,0024	0,0026	0,0004	0,0002	0,0136
10 GHz	0,0006	0,0007	0,0008	0,0008	0,0001	0,0001	0,0043

The amounts of electrical conductivity and alternating current have an important effect on the frequency [6].

Javadi *et al.*, [7] produced a composite aluminum matrix in order to determine its electrical properties and compare it with the matrix alone. Aluminum was used with the addition of particles of titanium diboride (TiB_2). First, the particles were prepared by mixing them for three hours, then drying the TIB_2 for 60 minutes at 120 degrees Celsius in a vacuum oven. Aluminum metal was heat and melt at 850 degrees Celsius in the presence of argon gas, with TIB2 set to it, and mixing continued for 600 seconds at 120 degrees in order to make a good casting. Three samples were taken and Scanning Electron Microscopy (SEM) images were taken, which revealed the visibility of TiB_2 grains, which in turn contributed to reducing the electrical conductivity of the Al–TiB_2 compound, which began to decrease with the increase in the percentage of TIB_2. While the conductivity rate was the highest value without adding any particles, it was (2.8 μΩ.cm) for pure aluminum. Dare *et al.*, [8] A study was conducted by placing nanoparticles of aluminum nitride (nanofluids) with the base material called ethylene glycol (EG) in order to create and examine the aluminum (nitride/ethylene glycol (AlN/EG)) compound to study the effect of changes in electrical conductivity. That the nanomaterial was taken in various proportions starting from (0.5, 1, 2, 3, 4, and 5) % by weight. In this study, the pro meter is used to measure the electrical conductivity of various liquids. In general, this meter is considered an important tool in evaluating the efficiency of electrical wires and their ability to better withstand electrical current. Also, the increase in AlN particles is directly related to the electrical conductivity, so the conductivity increases with the increase of the particles that were used, with a size of 65mm to 75mm. Jaber *et al.,* [9] used Tio_2 nanoparticles ,adding them by mixing and casting them with aluminum alloy (AA6063-T4). The weights used are 3%, 5% and 7% by weight, which represents titanium dioxide (Tio_2). The conductivity of aluminum increased with the increase in the percentage of titanium dioxide, and the conductivity also increased with increasing frequency amounts. SEM was also conducted and it was found that the aluminum sample with a content of 7% of titanium dioxide is the one that excels in nano distribution and has less porosity. Hussein *et al.,* [15] reinforced the basic matrix with ferric oxide reinforcements (Fe_2o_3) and aluminum oxide (Al_2o_3). Fe_2o_3 was applied at concentrations of (1.5 wt%), (2.5 wt%) and (5 wt%). 2% aluminum oxide is used. The basic matrix is finely ground metal for pure aluminium. The technique used to create the samples is powder metallurgy. Nano components contributed to improving the electrical and magnetic properties effectively. The frequency was also evaluated as having an inverse relationship with the relative permittivity result.

2. Methodology

2.1 Composite Fabrication

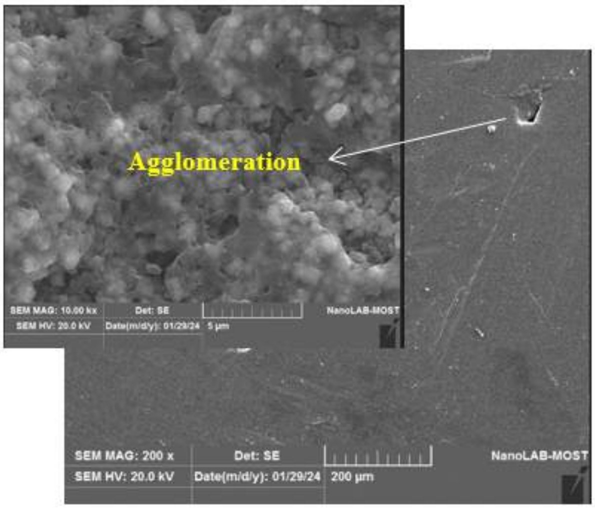
In this work, a heated crucible was used to place pure aluminum metal inside it, which is also heated for a certain period inside the crucible, and chromium and magnesium are added to it in weights in proportions of 3.8 g and 0.66 g with continuous heating at a temperature of 750 ℃. A Crucible is a container in which all materials are placed with the aim of melting them completely. After melting, warm Tio_2 nanoparticle additives wrapped in silicone are applied. When placing it, it should be emphasized that the temperature of the total mixture must be raised to 850 ℃. Tio_2 that used has a molecular size of (30 - 50) nm. In the final step, the resulting composite melt was poured into a mold with specific dimensions (220,10) mm, which represent the length and diameter, respectively. The resulting molds are shaft-shaped samples, three of them are AA5052 type, the first contains 0% Tio_2, the second contains 3% Tio_2 and the third contains 5% Tio_2. The samples are prepared using stir casting technique.

2.2 Experimental Procedure

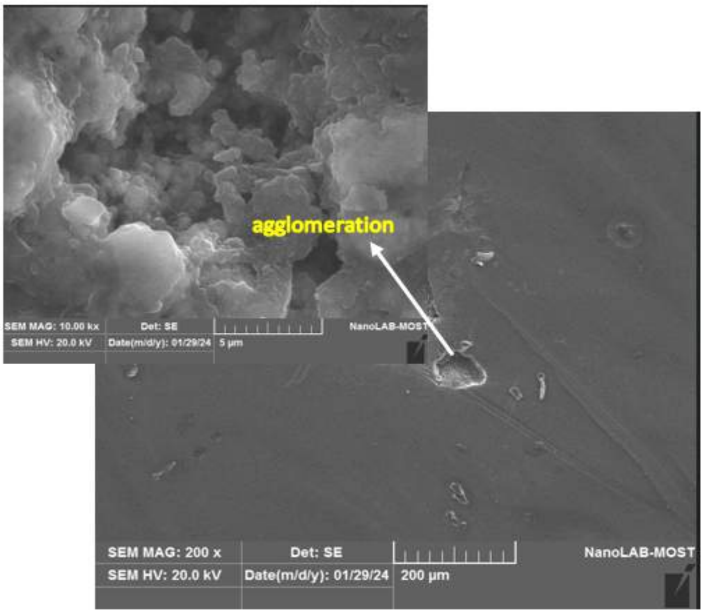
For the purpose of analyzing the microstructure of an aluminum matrix composite doped with $\boldsymbol{Tio_2}$ with different relative contents and manufactured by stir casting method. Small, testable pieces were cut using CNC machines. The aluminum composite samples were polished well to see the exact content of the samples by SEM examination. SEM examination and electrical tests were carried out on samples with length of 4.5 mm and dimension of 11 mm. Electrical tests were carried out with a device called Agilent from the USA, which was carried out at the room temperature. This device measures at frequencies from 50Hz-5MHz, and through impedance it gives conductivity values at each frequency. The conductivity measured at alternating current voltage (AC) has a value of oscillator level (osc) with 500 mv.

3. Results
3.1 Microstructure Results

Scanning microscopic images SEM were taken using a micrometer scale, which accurately documents the images. Images were taken of two matrix samples of AA5052-3% $\mathrm{Tio_2}$ and AA5052-5% $\boldsymbol{Tio_2}$ by wt. The microscopic figures show discipline in casting the sample because it is free of holes, due to good mixing of materials during the casting of aluminum composite samples using the stir casting method, which leads to good electrical properties. In the microscopic images, the presence of distributed $\mathrm{Tio_2}$ particles is shown, which they appear in tree and spherical forms. $\mathrm{Tio_2}$ particles are often 90% homogeneous in distribution, but they also contain places where there are agglomerations. This homogeneity results from the reasonably high temperature during the casting process, which has a role in reducing grain size amounts, which contributes to improving the mechanical properties of the materials [10]. The appearance of agglomeration occurs due to the micrometer scale being larger than its surface area [11]. The appearance of agglomeration is due to the fact that the titanium dioxide nanomaterial is characterized by the branching of its dendritic structures, which increases the surface area of the material, which is also responsible for the increase in surface tension [12] . At this work it was observed that agglomerations had increased in the sample with AA5052-5%$\mathrm{Tio_2}$ in certain areas, noting that this small agglomeration does not cause sample failure, as the two samples are free of cracks and can withstand pressure, as shown in Figure 2**.**



(a)



(b)

Fig. 2. SEM images of Al5052/TiO_2 nanocomposites (**a**) 3wt %, (b) 5wt.%

3.2 Electrical Results

An analysis of the electrical test was conducted on samples that were cast from aluminum and its compounds, which include (AA5052, AA5052+3% Tio_2 and AA5052+5% Tio_2). The test was carried out by Principle called (between the electrodes), which was done using an Agilent device, model 249A, made in USA. The goal of the electrical test is to calculate the phenomenon of skin effect and know its results after nano-additions of Tio_2. The skin depth can be calculated from the following relationship [16]:

$$\delta = \sqrt{\frac{\rho}{\pi * f * \mu_r * \mu_\circ}} \quad (1)$$

where:

δ : skin depth (mm), ρ : resistivity , f : frequency (Hz), μ_r: relative permeability =1 for aluminum,

$\mu_\circ$: $magnetic\ vacuum$ permeability =4*10^{-7} H/m.

The samples are tested and the resistivity is calculated through impedance. As for the frequency, the device calculates it, which reached 5 MHz.
Figure 3 shows the relationship between the emerging frequency and the skin depth for different reinforcements.

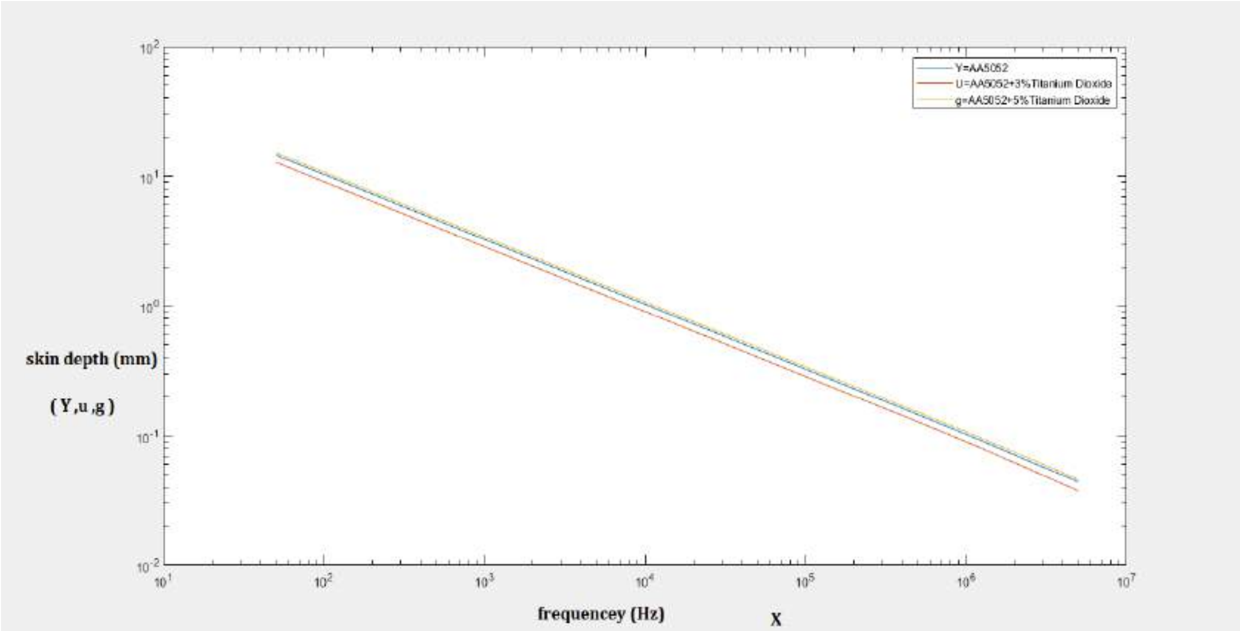


Fig. 3. Skin effect phenomenon of aluminum

Skin depth was measured when comparing the three aluminum samples together. It has been found when the frequencies are lower, the skin effect phenomenon is high. At the frequency of 50 Hz, the skin effect reached its peak in all aluminum samples. At a frequency of 50 Hz, it was observed that the aluminum sample AA5052&5%$Tio_2$with a percentage of Tio_2 obtained the highest amount of skin depth, reached to 15.2 mm, while the sample AA5052&3%Tio_2 appeared at 12.81 mm. As for AA5052, which does not contain Tio_2 nanomaterial, the skin depth reached 14.579 mm at the same frequency used. The amount of skin effect decreases as frequency increases. It was observed that for the first sample of aluminum devoid of titanium dioxide nanoparticles, the skin effect drop reached to 0.044152 mm, and this occurred at the last frequency measured at 5 MHz. The same was true for the other two samples at the same frequency, and their quantity also decreased. In general, when comparing the three samples with each other, it was found that the lowest rate of skin effect was when the addition rate was 3% of Tio_2 nanoparticles, and the highest rate was when 5% of the same nanomaterial that was added to the aluminum during the casting process. The results show in Table 2.

Table 2
The results of skin effect for aluminum with different weight of nanocomposite

Frequency (Hz)	AA5052+0% Tio_2 Skin Depth 1	AA5052+3% Tio_2 Skin Depth2	AA5052+5% Tio_2 Skin Depth3
50	14.5798	12.81	15.207
25050	0.6514	0.5722	0.6793
200048	0.2303	0.2022	0.2403
500045	0.1454	0.1278	0.152
750043	0.1185	0.104	0.1237
1000040	0.1024	0.0898	0.107
1250038	0.0913	0.08	0.0954
1500035	0.083	0.0726	0.0868
1725033	0.0772	0.0675	0.0808
1975030	0.0719	0.0626	0.0753
2200028	0.0678	0.0593	0.0711

2425026	0.0644	0.0559	0.0677
2675023	0.0611	0.0529	0.0643
2925021	0.0583	0.0503	0.0614
3175018	0.0558	0.0481	0.059
3425016	0.0536	0.0461	0.0565
3675013	0.0517	0.0443	0.0545
3950011	0.0498	0.0427	0.0525
4200008	0.0483	0.0412	0.0509
4500005	0.0466	0.0397	0.049
4750003	0.0453	0.0386	0.0475
5000000	0.04415	0.0375	0.046

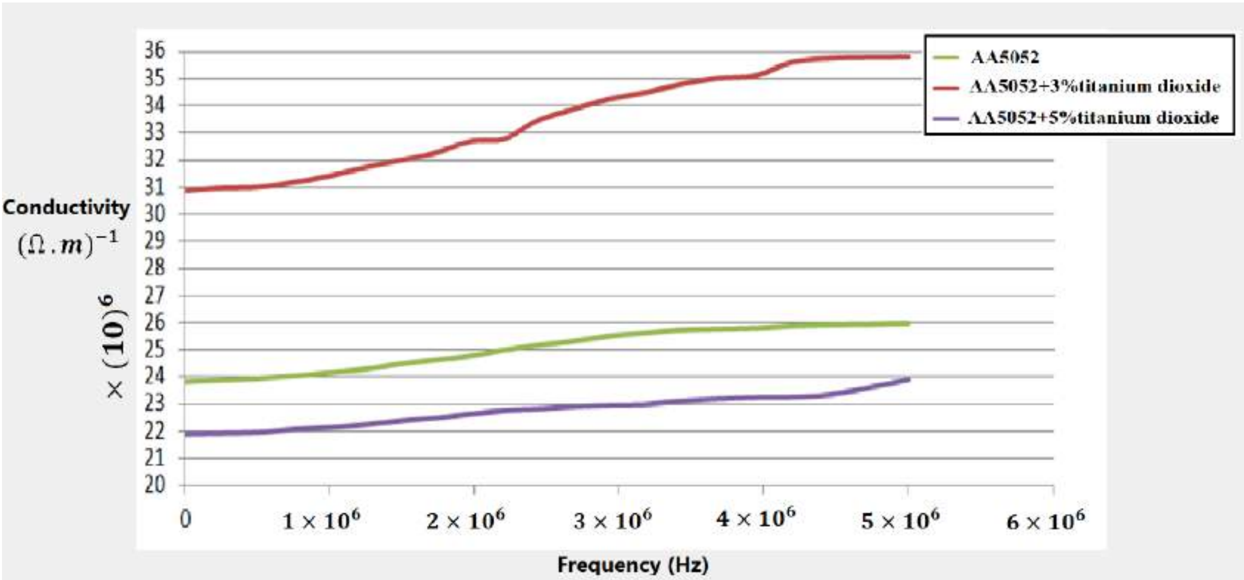


Fig. 4. Conductivity-frequency diagram

In Figure 4 and Table 3 the relationship between frequency and conductivity of alternating current is presented. The frequencies started at 50 Hz, and as the frequency increased, the conductivity also increased in all samples tested. The conductivity was calculated at 50 Hz, the AA5052 + 0% Tio_2 sample has electrical conductivity of 23.8322 $(\Omega.m)^{-1}$, but when 3wt% of the titanium dioxide content is affected, it rises to 30.8462 $(\Omega.m)^{-1}$. Adding a reinforcement material can contribute to improve the material properties, such as mechanic and magnetic properties [15]. It is noted that nanoparticles (Tio_2) contributed to improve the conductivity clearly, which appeared when mixing 3% Tio_2 with aluminum while the conductivity of the sample decreased when mixed 5%/ Tio_2 with aluminum, the decrease reached 21.906. This decrease is probably a result of agglomeration that occurred in the sample that cut for testing, which was observed by performing the SEM. When 3% Tio_2 is added to AA5052 alloy, a complex intermetallic compound is formed consisting of the metal matrix (aluminum) and distributed Tio_2 particles inside it. These solid particles (Tio_2) work to reduce the interaction between the electrical electrons and the nucleus in the material, so there is a decrease in the amount of electrical conductivity. This decrease in conductivity is corrected and many agreed with it, as Moustafa *et al.,* [13] studied the electrical conductivity of AL-5052 aluminum, whose electrical conductivity reached to (18.2 * 10^6) S/m, which decreased to (10.1 * 10^6) S/m after placing Ti-B (0.99 wt.% of titanium (Ti) and 0.2 wt.% of boron (B)) by stir casting.

Table 3
The electrical conductivity and resistivity with frequency magnitudes for aluminum AA5052 and its compounds

	AA5052+0% Tio_2		AA5052+3% Tio_2		AA5052+5% Tio_2	
Frequency (Hz)	Resistivity $(\Omega.\text{m}) \times 10^{-6}$	Conductivity $(\Omega.\text{m})^{-1} \times 10^{6}$	Resistivity $(\Omega.\text{m}) \times 10^{-6}$	Conductivity $(\Omega.\text{m})^{-1} \times 10^{6}$	Resistivity $(\Omega.\text{m}) \times 10^{-6}$	Conductivity $(\Omega.\text{m})^{-1} \times 10^{6}$
50	0.04196	23.8322	0.0324	30.864	0.04565	21.906
25050	0.041957	23.834	0.03238	30.883	0.04563	21.915
200048	0.04188	23.88	0.0323	30.96	0.0456	21.93
500045	0.04174	23.9578	0.03225	31.0077	0.04552	21.9684
750043	0.04158	24.05	0.03207	31.182	0.0453	22.075
1000040	0.04137	24.172	0.03183	31.417	0.04514	22.1533
1250038	0.04114	24.307	0.03151	31.736	0.04494	22.252
1500035	0.04081	24.504	0.03124	32.01	0.04464	22.401
1725033	0.0406	24.631	0.031	32.258	0.04446	22.492
1975030	0.04034	24.7893	0.03058	32.701	0.04417	22.64
2200028	0.040	25	0.03051	32.776	0.04392	22.769
2425026	0.03972	25.176	0.02991	33.4336	0.04382	22.821
2675023	0.0395	25.3229	0.02953	33.864	0.04365	22.91
2925021	0.0392	25.51	0.0292	34.2466	0.04355	22.962
3175018	0.03901	25.63445	0.02898	34.4828	0.0435	22.988
3425016	0.03886	25.733	0.02874	34.795	0.04325	23.121
3675013	0.0388	25.773	0.02856	35.014	0.04311	23.196
3950011	0.03874	25.813	0.02847	35.1247	0.04302	23.245
4200008	0.03863	25.8866	0.02808	35.6125	0.04299	23.261
4500005	0.03856	25.9336	0.02796	35.765	0.04275	23.392
4750003	0.03853	25.9538	0.02793	35.804	0.04232	23.2695
5000000	0.03848	25.9875	0.02781	35.9583	0.04182	23.912

4. Conclusions

1. Three samples of AA5052 aluminum alloy were prepared by special melting and mold casting. The addition to the aluminum is of the nano type and includes different concentrations of Tio_2, represented by 0%, 3%, and 5% by weight.
2. Good electrical results were obtained due to good distribution of nanoparticles revealed by the examination in the SEM images, which show some small agglomerates but the samples are regular and free of pores.
3. At each specific concentration ratio, the conductivity varies and the skin effect also varies. The value of the skin rate is affected by the value of resistivity in a direct relationship.
4. At a frequency of 50 Hz, the conductivity of the sample consisting of 3% of titanium dioxide reached 30.864$\times 10^6$ $(\Omega.m)^{-1}$, this nanoscale amount makes it have a better conductivity than the basic sample that does not contain nano additives.
5. The percentage with AA5052-5% Tio_2 represents the highest rate of skin effect compared to the other two samples, which reached 15.207 at a frequency of 50 Hz.

References

[1] Aziz, Israa A., and Russul Bedien. "Effect of ZrO2 addition on microstructure and mechanical properties of Al-Zn-Mg alloy matrix composite." *Engineering and Technology Journal* 38 (2020): 1751-1757. https://doi.org/10.30684/etj.v38i12A.336

[2] Lateef, Haneen, and Saad M. Alib. "Comparison between the Effect of Adding MSGNP and B4C-WC Nanoparticles on the Metallurgical and Mechanical Characterization of Al-7075 Composites Produced by Stir Casting." *Engineering and Technology Journal* 41, no. 12 (2023): 1552-1566.

https://doi.org/10.30684/etj.2023.142697.1544
[3] Abdudeen, Asarudheen, Abdel-Hamid I. Mourad, Jaber Abu Qudeiri, and Aiman Ziout. "Evaluation of Characteristics of A390-SiC p Squeeze Cast and Gravity Cast Composites." In *2020 Advances in Science and Engineering Technology International Conferences (ASET)*, pp. 1-6. IEEE, 2020. https://doi.org/10.1109/ASET48392.2020.9118349
[4] Kumar, Naveen, and G. Irfan. "Mechanical, microstructural properties and wear characteristics of hybrid aluminium matrix nano composites (HAMNCs)–review." *Materials Today: Proceedings* 45 (2021): 619-625. https://doi.org/10.1016/j.matpr.2020.02.719
[5] Hofmann, Tobias, Tobias Helbig, Frank Schindler, Nora Salgo, Marta Brzezińska, Martin Greiter, Tobias Kiessling et al. "Reciprocal skin effect and its realization in a topolectrical circuit." *Physical review research* 2, no. 2 (2020): 023265. https://doi.org/10.1103/PhysRevResearch.2.023265
[6] Reja, Ahmed H. "Investigation the Creep-Fatigue Behavior and AC Electrical Conductivity of AA 6061 Under Ultrasonic Peening." *Engineering and Technology Journal* 37, no. 11 Part A (2019). https://doi.org/10.30684/etj.37.11A.1
[7] Javadi, Abdolreza, Shuaihang Pan, Chezheng Cao, and Xiaochun Li. "High strength and high electrical conductivity Al nanocomposites for DC transmission cable applications." *Journal of Composites Science* 5, no. 7 (2021): 172. https://doi.org/10.3390/jcs5070172
[8] Ezekwem, Chidozie, and Ademola Dare. "Thermal and electrical conductivity of Aluminium Nitride nanofluids." *International Journal of Nano Dimension* 11, no. 1 (2020). https://doi.org/10.1080/15567036.2020.1792591
[9] Jaber, Manal Hadi, Ghada Adel Aziz, Alia Jasim Mohammed, and Hussain J. AL-AlKawi. "Electrical conductivity, magnetic and fatigue properties of aluminum matrix composites reinforced with nano-titanium dioxide (TiO2)." *Nanocomposites* 6, no. 2 (2020): 47-55. https://doi.org/10.1080/20550324.2020.1769976
[10] Kadhim, Zahraa Jawad. November, 2021. "Influence of Sintering Temperature on Mechanical and Electrical Properties of Aluminum Type AA5052 Matrix Composites," .
[11] Saravanan, S., and R. S. Dubey. "Optical and morphological studies of TiO2 nanoparticles prepared by sol–gel method." *Materials Today: Proceedings* 47 (2021): 1811-1814. https://doi.org/10.1016/j.matpr.2021.03.207
[12] Murugadoss, Sivakumar, Frederic Brassinne, Noham Sebaihi, Jasmine Petry, Stevan M. Cokic, Kirsten L. Van Landuyt, Lode Godderis et al. "Agglomeration of titanium dioxide nanoparticles increases toxicological responses in vitro and in vivo." *Particle and fibre toxicology* 17, no. 1 (2020): 10. https://doi.org/10.1186/s12989-020-00341-7
[13] Moustafa, Essam B., Mashhour A. Alazwari, Waheed Sami Abushanab, Emad Ismat Ghandourah, Ahmed O. Mosleh, Haitham M. Ahmed, and Mohamed A. Taha. "Influence of friction stir process on the physical, microstructural, corrosive, and electrical properties of an Al–Mg alloy modified with Ti–B additives." *Materials* 15, no. 3 (2022): 835. https://doi.org/10.3390/ma15030835
[14] Keller, Reto B. *Design for electromagnetic compatibility--in a nutshell: theory and practice*. Springer Nature, 2023. https://doi.org/10.1007/978-3-031-14186-7
[15] Aljawad, Hussain A., H. J. M. Alalkawi, and Ghada Adel Aziz. "Compression strength, dielectric and magnetic properties of new aluminium matrix hybrid nanocomposites." In *IOP Conference Series: Materials Science and Engineering*, vol. 765, no. 1, p. 012056. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/765/1/012056
[16] Cai, Rong, Yingshuang Hu, Miao Yu, Wenyu Liao, Lufeng Yang, Aditya Kumar, and Hongyan Ma. "Skin effect of chloride ingress in marine concrete: A review on the convection zone." *Construction and Building Materials* 262 (2020): 120566. https://doi.org/10.1016/j.conbuildmat.2020.120566
[17] Pranav, A., and A. Muniappan. "Comparing carbide insert and high speed end mill cutter for material removal rate in the end milling process of Al6061/SiC/graphite aluminum composite." In *AIP Conference Proceedings*, vol. 2853, no. 1, p. 020051. AIP Publishing LLC, 2024. https://doi.org/10.1063/5.0197529
[18] Kaliappan, S., Pranav Kumar Prabhakar, Joseph Manuel, Pravin P. Patil, M. Sathya Prakash, and Baskara Sethupathy Subbaiah. "Recent advancements in aluminum metal matrix composites: A review of processing and application." In *AIP Conference Proceedings*, vol. 2800, no. 1, p. 020130. AIP Publishing LLC, 2023. https://doi.org/10.1063/5.0168369
[19] Adetunla, Adedotun, Fiseye Fidudusola, Henry Benjamin, Omolayo Ikumapayi, and Esther Akinlabi. "Investigating the mechanical integrity of friction stir processed 7075 aluminum alloy impregnated with various reinforcements." In *AIP Conference Proceedings*, vol. 3101, no. 1, p. 020005. AIP Publishing LLC, 2024. https://doi.org/10.1063/5.0214596
[20] Basori, Imam, Naga Bonar Sinaga, Mahardika Sandy Ponco, Yunita Sari, and Siska Titik Dwiyati. "Investigation of aluminum addition on the microstructure and mechanical properties of Cu-31Zn-0.1 Mn-xAl alloys." In *AIP Conference Proceedings*, vol. 3116, no. 1, p. 060003. AIP Publishing LLC, 2024. https://doi.org/10.1063/5.0210382

[21] Rashid, Waleed T. "Effect of Mg percentage and weight fraction of yttrium oxide on the tensile strength of aluminum matrix composite (Al-6061/Y2O3)." In *AIP Conference Proceedings*, vol. 3002, no. 1, p. 080026. AIP Publishing LLC, 2024. https://doi.org/10.1063/5.0205902

[22] Salah, Shams Alaseel, Khansaa D. Salman, and Suad A. Aessa. "Improving the microstructure and mechanical properties of the nanocomposite's material (Al+ ZnO)." In *AIP Conference Proceedings*, vol. 3002, no. 1, p. 080012. AIP Publishing LLC, 2024. https://doi.org/10.1063/5.0208269

[23] Seikh, Ziyauddin, Mukandar Sekh, Sandip Kunar, Golam Kibria, Rafiqul Haque, and Shamim Haidar. "A study on various applications of aluminium metal matrix composites." In *AIP Conference Proceedings*, vol. 2764, no. 1, p. 070009. AIP Publishing LLC, 2023. https://doi.org/10.1063/5.0144283

[24] Agarwal, Yash, Ashok Kumar Sharma, and Vimal Kumar Pathak. "Marble dust filled aluminium metal alloy composites in bearing application: A review." In *AIP Conference Proceedings*, vol. 2835, no. 1, p. 020013. AIP Publishing LLC, 2024. https://doi.org/10.1063/5.0222136

[25] Chawla, Dinesh, Manoj Nayak, and Pallav Gupta. "Fabrication aspect and mechanical properties of aluminium metal matrix composites: A perspective." In *AIP Conference Proceedings*, vol. 2800, no. 1, p. 020266. AIP Publishing LLC, 2023. https://doi.org/10.1063/5.0162962

[26] Basori, Imam, Naga Bonar Sinaga, Mahardika Sandy Ponco, Yunita Sari, and Siska Titik Dwiyati. "Investigation of aluminum addition on the microstructure and mechanical properties of Cu-31Zn-0.1 Mn-xAl alloys." In *AIP Conference Proceedings*, vol. 3116, no. 1, p. 060003. AIP Publishing LLC, 2024. https://doi.org/10.1063/5.0210382

[27] Topolski, Łukasz, Jurij Warecki, and Zbigniew Hanzelka. "Methods for determining power losses in cable lines with non-linear load." *Przeglad Elektrotechniczny* 94, no. 9 (2018): 85-90. https://doi.org/10.15199/48.2018.09.21