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Effect of Freshwater and Seawater Immersion on Mechanical Properties and Pre-Immersion Magnetic Response of Silicone Rubber–Magnetite Composite Magnets

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ABSTRACT

Magnetite (Fe_3O_4) and RTV 48 silicone rubber-based magnetic composites have potential for outdoor applications due to their flexible and tunable magnetic properties. This study investigates the effect of immersion for 14 days in fresh water and seawater on its mechanical, magnetic, and thermal properties. Specimens were made by mixing 70 wt% Fe_3O_4 powder into RTV 48 matrix, then tested for hardness using Shore A durometer, magnetic properties using Vibrating Sample Magnetometer (VSM), and thermal stability using Thermogravimetric Analysis (TGA). Results showed a decrease in surface hardness due to matrix degradation by water penetration. The magnetic properties continued to exhibit soft magnetic characteristics with low coercivity and remanence. TGA analysis revealed changes in thermal degradation patterns, signaling chemical interactions between the material and the wet environment. These findings suggest that exposure to water can affect the long-term performance of Fe_3O_4-RTV 48 composites, making moisture resistance an important aspect for their outdoor applications.

1. INTRODUCTION

Magnets are a type of material that can attract metals. Magnets have been applied to various industrial fields (Nagarajan et al., 2021 ; Hojjati-Najafabadi et al., 2022). So it is necessary for magnetic materials that are not only strong in magnetic properties but also have good mechanical properties. To answer the challenges of modern industry that leads to efficiency, durability, and speed, composite magnets are the best solution. Composite itself is a type of material that consists of two or more different materials that are combined, resulting in a new material with different properties from its constituent materials. Composite magnets are a combination of magnetic materials and non-magnetic binders. Magnetic materials usually use magnetic powders (García-Martín et al., 2022; Grujić et al., 2023; Wang et al., 2023). NdFeB, Fe_3O_4, and Barrium Ferrite are types of magnetic metal powders that are often used in composite magnets. This research will use Fe_3O_4 as the magnetic powder. Binder materials in composite magnets are added to provide elastic mechanical properties, and have high strength . Various types of polymers are suitable to be used as binders. A polymer material that has high elasticity and is

easy to process is Room Temperature Vulcanized (RTV) silicon rubber (Huang et al., 2022; Mazlum & Celik, 2025b). There are many types of RTV but the one that will be used in this research is RTV 48 because it has good elastic properties and is easy to obtain.

Fe_3O_4 is a type of softmagnetic. Softmagnetic is a magnet that cannot become a permanent magnet but can become an induction magnet. This softmagnetic property can be seen from the thin hysteresis curve and has a high magnetic saturation. This type of magnet is suitable for dynamic applications such as Brushless Direct Current (BLDC) motors, actuators, robots, and transformers (Hoz et al., 2023). Fe_3O_4 powder, commonly called magnetite powder, is a type of metal oxide mineral nanoparticle. Naturally, several types of magnetic minerals exist, such as magnetite (Fe_3O_4), hematite (α-Fe_2O_3), and maghemite (γ-Fe_2O_3), which have great potential in industrial development (Yunita et al., 2019; Ningtyas et al., 2024). Fe_3O_4 composite magnets with RTV 48 binder will produce induction magnet materials that not only have high induction magnetic properties but will also have high mechanical resistance. The composition of the composite magnet will greatly affect the properties that will be produced later (Ramlan, 2020). Mixing Fe_3O_4 powder into RTV 48 can influence the magnetic and mechanical properties of the composite. In this study, a fixed composition was used to specifically evaluate the effects of freshwater and seawater immersion on the composite's performance.

Composite magnets are expected to be applied to various types of environments. Resistance to extreme environments such as seawater is an important priority in the development of composite magnets. This is due to the widespread application of magnets in environments where water exposure is prevalent. One notable application is in the mitigation of pollution in aquatic environments (Ningtyas et al., 2024). Therefore, the resistance of silicone rubber composite magnets to aqueous environments becomes critically important. Corrosive seawater is a challenge in itself, but fresh water can also degrade silicon rubber (Arifin et al., 2024). In the research of Wibowo et al. (2021) Magnetorheological elastomers (MRE) material with RTV binder, when experiencing salt water immersion there is a decrease in hardness value (Wibowo et al., 2021).However, the two previous studies were limited to magnetorheological elastomer (MRE) materials and had not yet been extended to magnetic composite materials. The purpose of this study is to determine the effect of seawater and freshwater immersion on the hardness properties, thermal properties, and magnetic properties of Fe_3O_4 composite magnets with RTV 48 binder. Investigating the effects of seawater and freshwater immersion on Fe_3O_4 composite magnets provides valuable insights into their degradation behavior, supporting the development of environmentally durable composite magnets.

2. METHOD

2.1 Materials

Main material used in this research was magnetite (Fe_3O_4) powder, serving as the magnetic filler. This powder was mixed with RTV-48 silicone rubber, acting as the polymer matrix. RTV 48 was purchased from an online marketplace and used without further purification. The curing of the silicone rubber was triggered by adding the RTV-SB catalyst, enabling the crosslinking reaction to occur at room temperature (Rubinsztajn et al., 2025).

2.2 Material Preparation

The Fe_3O_4 powder was mixed using a mechanical mixer. The composition of the mixture consists of 70% powder and 30% RTV 48. 70:30 was chosed because it is a balanced composition between magnetic and mechanical properties. The preparation process is illustrated in Figure 1.

The Fe_3O_4 content was selected at 70 wt% to ensure dominant magnetic properties while maintaining structural stability. To achieve a uniform mixture in the specimen, hand mixing was performed for approximately 5 minutes. The 70% composition was also chosen to enhance both the magnetic and mechanical properties of the composite. After obtaining a homogeneous mixture, the RTV-48 catalyst (methyl ethyl ketone peroxide) was added to initiate polymerization. The mixture was then immediately poured into acrylic molds. After polymerization, the specimen was obtained as shown in Figure 2

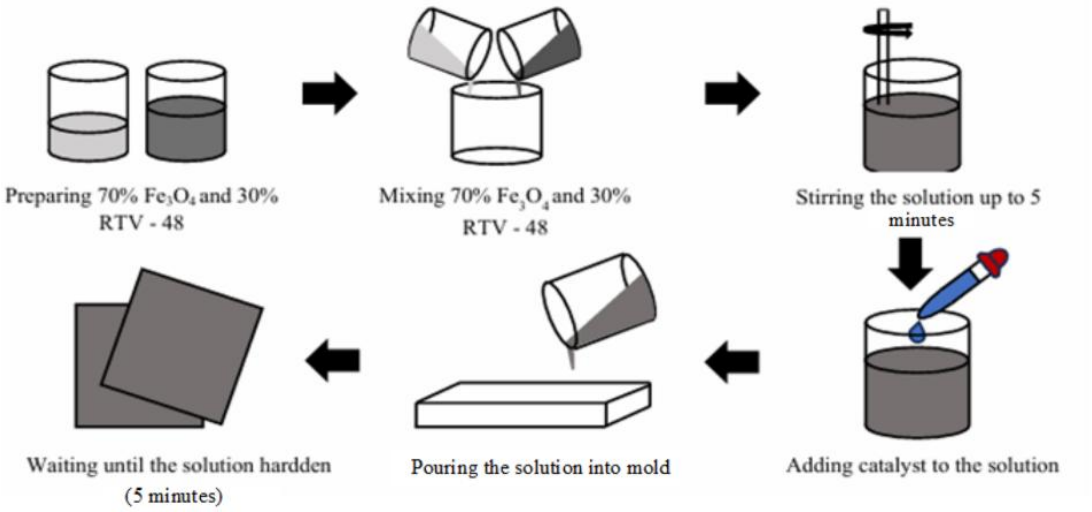


Figure 1 Material Preparation Scheme

Figure 2 specimen after polymerization

After polymerization was complete, the specimen was cut into a 3x3 cm in size with a thickness of 6 mm, as illustrated in Figure 3(a). The actual specimen after cutting is shown in Figure 3(b).

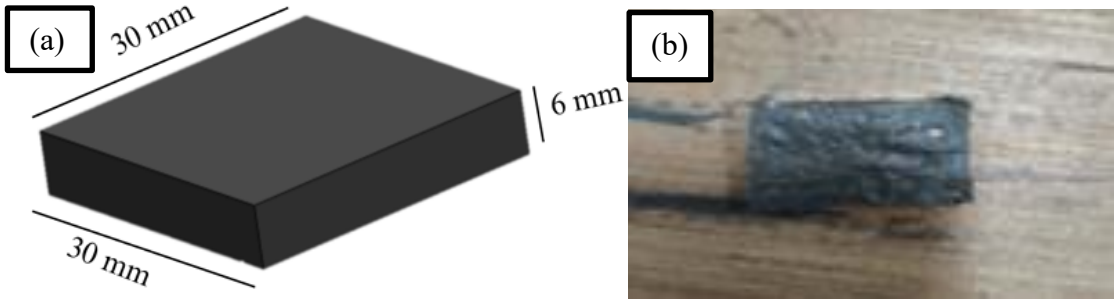


Figure 3 Specimen dimension after cutting: (a) schematic illustration, (b) real specimen.

2.3 Water Immersion Procedure

The specimens were subjected to immersion in two types of solutions, namely seawater and freshwater, for a duration of 14 days. The seawater was collected from Nampu Beach, Wonogiri Regency, at the coordinates 8°12'37.8" S (South Latitude) and 110°54'04.6" E (East Longitude).

2.4 Characterization

Vibrating Sample Magnetometer (VSM) was used in this testing to analyze the magnetic characteristics of the composite magnet, which were then visualized in the form of a hysterisis curve. Figure 4 shows the type of VSM used for the testing.

Figure 4 Vibrating Sample Magnetometer (Versa Lab)

Hardness testing was measured using a Shore-A Durometer, following the ASTM-D2240 standard. The hardness test was conducted using a Shore-A durometer, illustrated in Figure 5. Measurements were taken at five different points on the specimen surface, with readings recorded 15 seconds after each measurement point. The average of these readings was then calculated to obtain the hardness stability value.

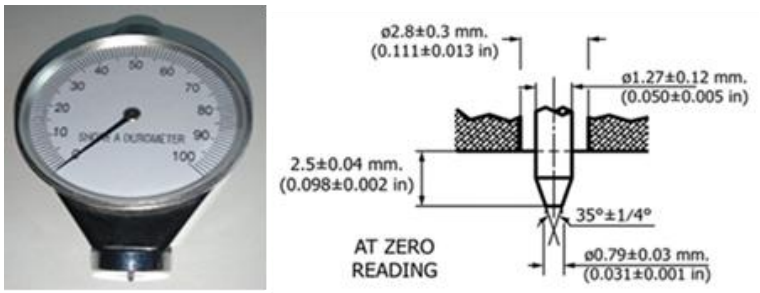


Figure 5 Shore A durometer

Thermal analysis was conducted using Thermogravimetric Analysis (TGA) with a Linseis STA PT 1600: TG-DSC instrument. The TGA heating process was carried out in an air atmosphere, starting from room temperature up to 500°C, with a heating rate of 10°C/min. TGA analysis followed ASTM-E1131 to determine mass composition based on the percentage of inorganic residue after polymer combustion. While ASTM-E2550 used to asses thermal stability by comparing degradation temperatures before and after oven heating treatment. The TGA data were also analyzed to identify the main thermal decomposition stages of RTV 48 and the associated degradation products, based on weight-loss patterns and literature references.

3. RESULTS AND DISCUSSION

3.1 Surface Property

As shown in the Figure 6, the specimen exhibits visible rust after seawater immersion. The corrosion on the Fe_3O_4–RTV 48 composite surface is triggered by the high concentration of chloride ions (Cl^-) in seawater. These aggressive ions can penetrate the silicone matrix, especially through defects or pores, reaching Fe_3O_4 particles and promoting further oxidation into compounds like Fe_2O_3 or $Fe(OH)_3$, which appear as reddish-brown rust.

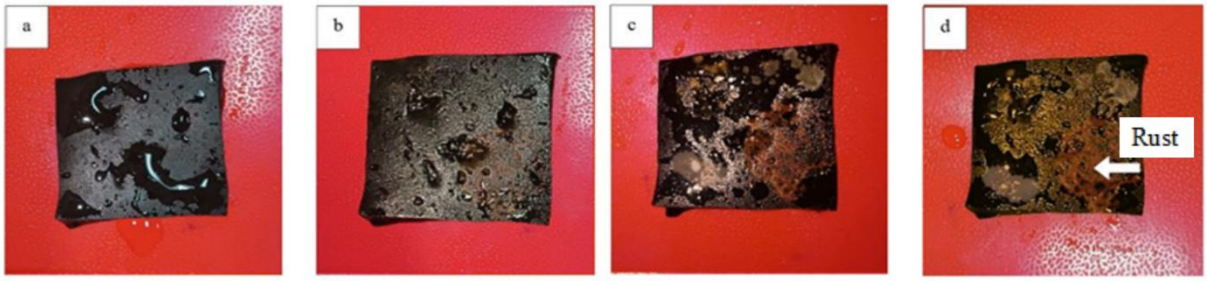


Figure 6 Surface Property of Fe_3O_4–RTV 48 composite with Salt Water Immersion (a) 1 Day Immersion, (b) 5 Days Immersion, (c) 10 Days Immersion, (d) 14 Days Immersion.

In Figure 7(a) and 7(b), no noticeable changes are observed, but in Figure 7(c) and 7(d), a thin shiny film appears on the specimen surface. This glossy layer on the Fe_3O_4–RTV 48 composite after freshwater immersion is likely due to the migration of additives or residual siloxanes present in RTV silicone. These components can leach out and form a smooth, thin film on the surface after prolonged water exposure. RTV silicone such as RTV 48 usually contains additives like plasticizers or residual curing agents such as volatile siloxanes. When immersed in water, these components can partially dissolve and migrate to the surface, forming a thin slippery layer.

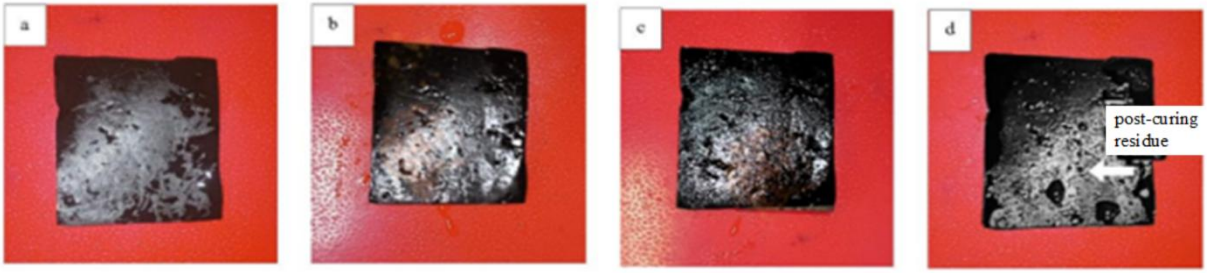


Figure 7 Surface Property of Fe_3O_4–RTV 48 composite with Fresh Water Immersion (a) 1 Day Immersion, (b) 5 Days Immersion, (c) 10 Days Immersion, (d) 14 Days Immersion.

3.2 Hardness Testing (Shore-A Durometer)

The effect of immersion on the hardness of the magnetic composite material was evaluated using the Shore A Durometer test. This test conducted at five points with an indentation depth of 2.5 mm, including a 15-second delayed reading to assess stability. Figure 8 presents the Shore A hardness values obtained from the test.

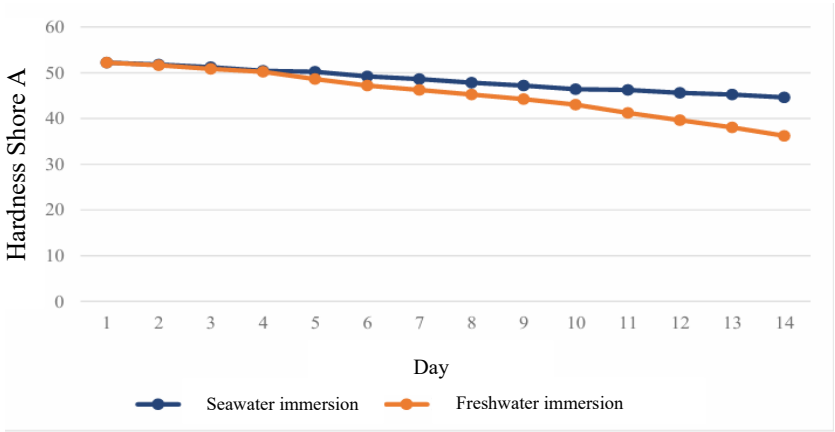


Figure 8 Hardness Test Results Using Shore-A Durometer

The hardness of the composite decreased with increasing immersion time in both freshwater and seawater. The unexposed specimen had an average from five different points on Shore A hardness of 52 Shore A, which declined after immersion. On day 14, the specimen immersed in freshwater

recorded a hardness of 40.2, while that in seawater measured 44.6. This indicates that immersion treatment reduces the hardness of the material. Freshwater exposure led to a greater reduction in hardness compared to seawater, likely due to higher water absorption. This is attributed to seawater's higher salinity, which increases its osmotic pressure and makes it more difficult to diffuse into the specimen. The presence of ions such as Na^+ and Cl^- in seawater forms hydrated ion shells with a larger effective molecular size than pure H_2O, further limiting diffusion. into the material. The reduction in hardness is therefore associated with water diffusion, which weakens the physical integrity of the magnetic composite.

3.3 Magnetic Properties Testing

Figure 9 below shows the hysteresis curve of the composite magnet based on Fe_3O_4 powder and RTV-48. The curve indicates soft magnetic characteristics, as evidenced by its thin/narrow shape, which reflects low coercivity, low remanence, and relatively high magnetic saturation.

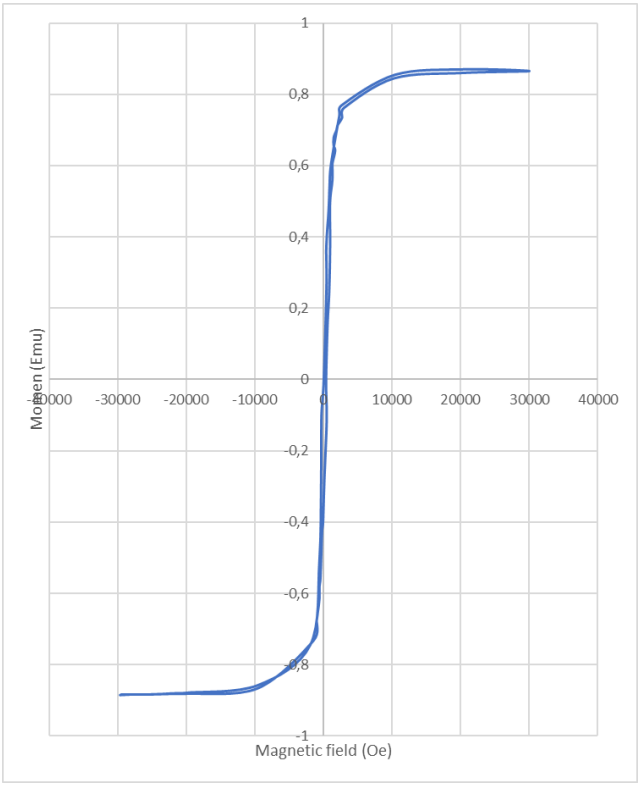


Figure 9 Hysteresis Curve Result of Untreated Specimen

The hysteresis curve from the VSM test confirms that the Fe_3O_4-based magnetic composite is a soft magnetic material. This is indicated by its low coercivity (~126 Oe), shown by a narrow, symmetric loop near H = 0; low remanent magnetization (<0.5 emu), meaning minimal residual magnetization after the external field is removed; and relatively high saturation magnetization (~1.3 emu), reflecting a strong magnetic response. These characteristics make the composite suitable for dynamic electromagnetic applications (Doloksaribu et al., 2019 ; J. Li et al., 2021).

The data presented are limited to the pre-immersion condition, as the VSM test results for the sample prior to immersion exhibited very minimal soft magnetic properties. Consequently, the VSM results for the other samples are expected to show no significant differences.

3.4 Thermal Stability Testing (TGA)

TGA testing based on ASTM-E1131 standard was used to determine the final residual mass of the polymer (specifically silicone rubber) based on the mass change with respect to the temperature. Figure 10 presents the TGA test results of the composite magnets with Sea Water Immersion and with Fresh Water immersion for 14 days.

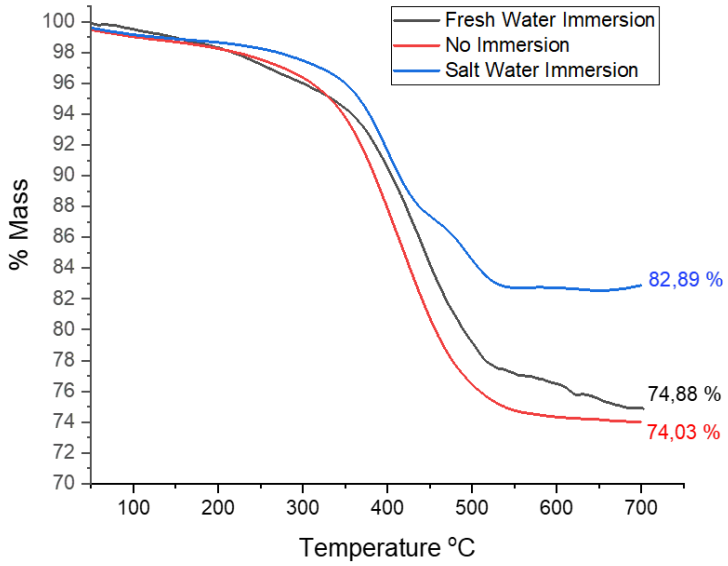
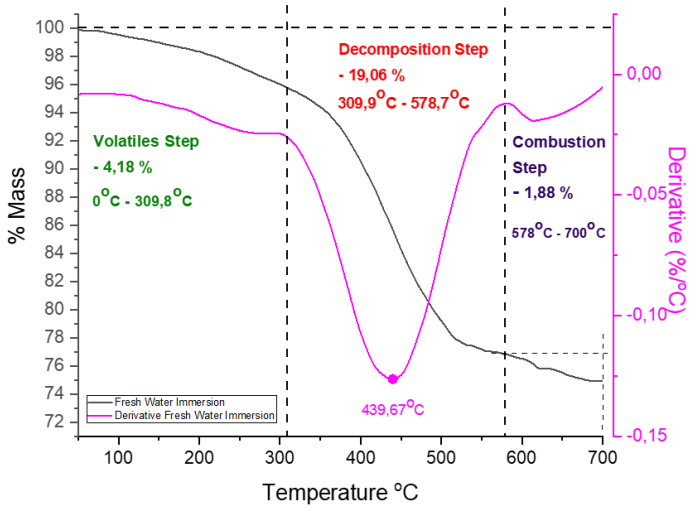


Figure 10 TGA Test Results

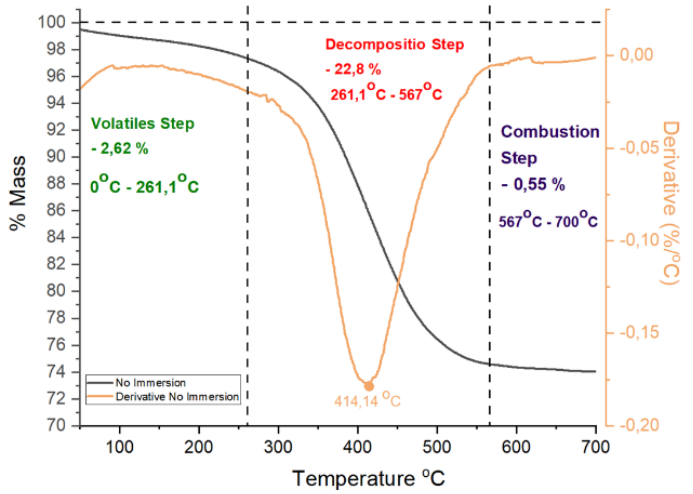
The specimen immersed in seawater (blue line) exhibited the smallest mass loss at 17.11%, while the untreated specimen (red line) and the one immersed in freshwater (black line) showed greater losses at 25.97% and 25.12%, respectively. This reduced mass loss in seawater may be attributed to the adsorption or reaction of impurity ions such as Na^+ and Cl^- with the surface of Fe_3O_4 particles or the RTV 48 matrix, forming a thin layer of inorganic salts(Kim & Yoo, 2019). Additionally, salt deposits on the specimen surface may contribute to the higher residual mass. The TGA curve also reveals the stages of thermal processes, identifiable by distinct plateaus and drops in the graph, which indicate different decomposition or transition phases within the material (Jubier et al., 2024).

In the initial stage, all three specimens experienced mass loss due to the release of volatile components and residual solvents such as H_2O, trimethylsilanol ($(CH_3)_3SiOH$), and hexamethyldisiloxane ($(CH_3)_3SiOSi(CH_3)_3$). The main decomposition stage represents the degradation of RTV 48, marked by the breakdown of siloxane polymer chains ($–[Si(CH_3)_2–O]–_n$), producing volatile gases like methane (CH_4) and carbon dioxide (CO_2), and leaving behind solid residues of amorphous silica (SiO_2) and carbon (C). Fe_3O_4 particles remain chemically stable at this stage. The final stage involves carbonization of remaining organics and defines the residual mass after heating. This residue mainly consists of thermally stable Fe_3O_4 particles, amorphous SiO_2 from RTV oxidation, and possibly residual carbon depending on the initial polymer network and decomposition efficiency.

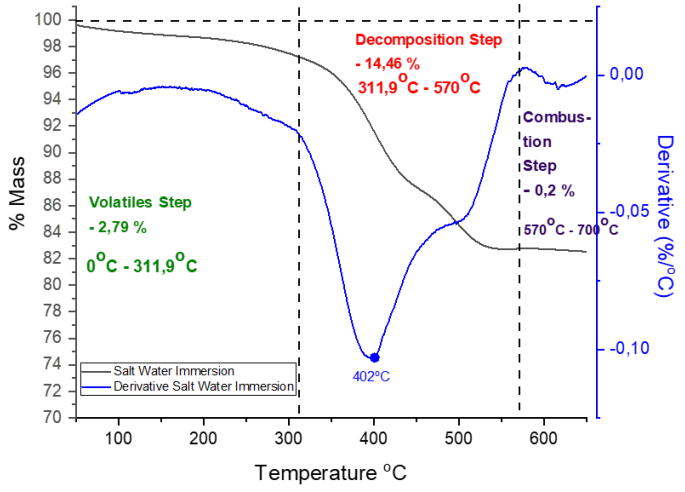
The DTGA graph shows distinct degradation peaks for each treated sample: 414.14 °C for the untreated specimen, 439.67 °C for the freshwater-immersed specimen, and 402 °C for the seawater-immersed specimen. The degradation peak indicates the temperature at which the material undergoes complete thermal decomposition. Therefore, the specimen immersed in freshwater exhibited the highest degradation resistance, as evidenced by its peak temperature of 439.67 °C. In contrast, the seawater-immersed specimen demonstrated the greatest susceptibility to degradation, reaching its maximum decomposition at 402 °C, which is substantially lower than the other two samples. At the initial stage, all samples exhibit mass loss due to the release of volatile components and residual solvents. The untreated sample showed a 2.62% mass loss, slightly lower than the seawater-immersed (2.79%) and freshwater-immersed specimens (4.18%), indicating greater absorption of water or weakly adsorbed ions in the immersed specimens. The main decomposition stage corresponds to the degradation of RTV 48. The untreated sample experienced the highest mass loss at 22.8%, compared to 19.06% (freshwater) and 14.46% (seawater). The lower mass loss in the immersed samples suggests interactions between water and siloxane groups during immersion, which may have initiated partial structural degradation through moisture-induced corrosion(Z. Li et al., 2022).



(a)



(b)



(c)

Figure 11. TGA Test Results with Derivative Analysis of (a) No Immersion (b) Fresh Water Immersion (c) Salt Water Immersion

4. CONCLUSION

Based on the investigation of the effects of freshwater and seawater immersion on the mechanical and magnetic properties of Fe_3O_4-based magnetic composites, it can be concluded that immersion significantly influences both hardness and thermal stability. The Shore A hardness decreased over time with immersion, from 52.2 in the untreated sample to 36.2 and 44.6 in freshwater- and seawater-immersed samples respectively after 14 days, indicating that water absorption weakens the polymer–filler interface. Magnetically, the composite exhibits soft magnetic characteristics, as confirmed by its narrow hysteresis loop and low coercivity, making it unsuitable for permanent magnet applications. Thermogravimetric analysis (TGA) showed the highest mass loss in the untreated sample (25.97%), followed by freshwater immersion (25.12%), and the lowest in seawater (17.11%), likely due to salt deposition and ion interaction. Furthermore, DTGA results showed that degradation peak temperatures varied among samples, with the untreated sample degrading at 414.14 °C, freshwater-immersed at 439.67 °C, and seawater-immersed at 402 °C, reflecting different thermal behaviour as a result of the immersion media.

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REFERENCE

Arifin, R. R. N., Lenggana, B. W., Ubaidillah, Wibowo, Aljabri, A., Yunus, N. A., & Al-Hemyari, A. K. A. (2024). Identification of stiffness and damping characteristics of magnetorheological elastomers due to immersion in seawater. *Journal of Asian Architecture and Building Engineering*, *00*(00), 1–17. https://doi.org/10.1080/13467581.2024.2407153

Doloksaribu, M., Virdhian, S., Resmana Djuanda, D., & Afrilinda, E. (2019). Peningkatan Koersivitas dan Remanen pada Magnet Permanen Nd-Fe-B dengan Proses Difusi Batas Butir. *Metal Indonesia*, *41*(1), 18–25.

García-Martín, E., Granados-Miralles, C., Ruiz-Gómez, S., Pérez, L., del Campo, A., Guzmán-Mínguez, J. C., de Julián Fernández, C., Quesada, A., Fernández, J. F., & Serrano, A. (2022). Dense strontium hexaferrite-based permanent magnet composites assisted by cold sintering process. *Journal of Alloys and Compounds*, *917*, 165531. https://doi.org/10.1016/j.jallcom.2022.165531

Grujić, A., Nedeljković, D., Stajić-Trošić, J., Stijepović, M. Z., Alnouri, S., & Perišić, S. (2023). Magneto-mechanical and thermal properties of Nd-Fe-B-epoxy-bonded composite materials. *Polymers*, *15*(8), 1894.

Hojjati-Najafabadi, A., Mansoorianfar, M., Liang, T., Shahin, K., & Karimi-Maleh, H. (2022). A review on magnetic sensors for monitoring of hazardous pollutants in water resources. *Science of the Total Environment*, *824*(86), 153844. https://doi.org/10.1016/j.scitotenv.2022.153844

Hoz, F. O. de la, Saavedra, E., Pereira, A., & Escrig, J. (2023). *Static and Dynamic Magnetic Properties of Fe3O4 Nanotubes*. *40*(4), 3015–3017. https://doi.org//10.3390/nano13071265

Huang, X., Song, G., Shi, J., Ren, J., Guo, R., Li, C., Chen, G., Li, Q., & Zhou, Z. (2022). Thermal stability, mechanical, and optical properties of novel RTV silicone rubbers using octa(dimethylethoxysiloxy)-POSS as a cross-linker. *E-Polymers*, *22*(1), 357–369. https://doi.org/10.1515/epoly-2022-0022

Jubier, N. J., Al-Jorani, K. R., Ali, A. A., Al –Bayaty, S. A., & Al-Uqaily, R. A. H. (2024). Thermal degradation assessment, impact strength, and hardness of combination epoxy and polystyrene powder composite. *Kuwait Journal of Science*, *51*(4), 100271. https://doi.org/10.1016/j.kjs.2024.100271

Kim, A. R., & Yoo, D. J. (2019). A comparative study on physiochemical, thermomechanical, and electrochemical properties of sulfonated poly (ether ether ketone) block copolymer membranes with and without Fe3O4 nanoparticles. *Polymers*, *11*(3), 536.

Li, J., Sepehri-Amin, H., Sasaki, T., Ohkubo, T., & Hono, K. (2021). Most frequently asked questions about the coercivity of Nd-Fe-B permanent magnets. *Science and Technology of Advanced Materials*, *22*(1), 386–403. https://doi.org/10.1080/14686996.2021.1916377

Li, Z., Cao, X., Cong, D., Song, K., Liu, X., Dong, J., & Zhou, Z. (2022). Corrosion Behavior and Magnetic Property Degradation of FeCrNiTi Soft Magnetic Materials in NaCl-containing environments. *International Journal of Electrochemical Science*, *17*, 1–13. https://doi.org/10.20964/2022.09.53

Mazlum, U., & Celik, I. (2025). Experimental determination of the compression behavior of RTV silicone rubber-based magnetorheological (MR) materials under static loading. *Journal of Magnetism and Magnetic Materials*, *614*, 172698.

Nagarajan, B., Wang, Y., Taheri, M., Trudel, S., Bryant, S., Qureshi, A. J., & Mertiny, P. (2021a). Development and characterization of field structured magnetic composites. *Polymers*, *13*(17), 2843.

Ningtyas, R. D., Yanti, D. D., Amin, A. K., & Aji, A. (2024). Fabrication of a Fe3O4/CS/AgNPs Composite from Indigenous Iron Sand for Enhanced Methylene Blue Adsorption. *Journal of Cluster Science*, *35*(5), 1463–1480. https://doi.org/10.1007/s10876-024-02594-0

Ramlan. (2020). Analisa Sifat Fisis, Sifat Mekanik dan Sifat Magnet pada Bonded Magnet NdFeB dengan Perekat Celuna. *Journal of Technical Engineering: Journal of Technical Engineering: Piston*, *3*(2), 1–5.

Rubinsztajn, S., Mizerska, U., Kurjata, J., Kwiatkowska, M., & Cypryk, M. (2025). Aldehyde-Assisted Alkoxysilane Condensation to Form Siloxane Bond: A New Process for Curing Alkoxy-Functional Silicone Resins. *Molecules*, *30*(3), 714.

Wang, Y., Ahmadi Moghaddam, H., Palacios Moreno, J., & Mertiny, P. (2023b). Magnetic filler polymer composites—morphology characterization and experimental and stochastic finite element analyses of mechanical properties. *Polymers*, *15*(13), 2897.

Wibowo, W., Lenggana, B. W., Ubaidillah, U., Ariawan, D., Imaduddin, F., Mazlan, S. A., & Choi, S. B. (2021). Declining performance of silicone-based magnetorheological elastomers after accelerated weathering. *Materials*, *14*(21), 1–14. https://doi.org/10.3390/ma14216389

Yunita, I., Sulistyaningsih, T., & Widiarti, N. (2019). Karakterisasi dan Uji Sifat Fisik Material Zeolit Modifikasi Magnetit sebagai Adsorben Ion Klorida dalam Larutan Berair. *Indonesian Journal of Chemical Science*, *8*(2), 87–92. https://doi.org/10.15294/ijcs.v7i2.20912