Study on modification of nano silica by [3- (2-Aminoethyl) aminopropyl] trimethoxy silane (KH-792) to reinforce polymer film based on epoxy resin Epon 1001X75

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Abstract
The surface of nano silica (NS) was modified by [3- (2-Aminoethyl) aminopropyl] trimethoxy silane (KH-792) to increase surface activity. Evaluate the efficiency of grafting [3- (2-Aminoethyl) aminopropyl] trimethoxy silane (KH-792) into NS was characterized by Fourier Transform Infrared Spectrometry (FTIR) and Thermo Gravimetric Analysis (TGA). NS and modified nano silica (m-NS) were dispersed into epoxy resin Epon 1001X75 by mechanical stirring and ultrasonic vibration. Epoxy resin Epon 1001X75 was cured with Epikure 3125 (Epi3125). The structural morphology and dynamic mechanical properties of materials were characterized by Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), and Dynamic Mechanical Analysis (DMA). The results showed that NS was modified with the content of 20 wt% KH-792 for the highest denaturation efficiency. With adding the content of 1 wt% NS (NS-1), the mechanical properties of epoxy polymer film Epon 1001X75/Epi3125/NS-1 increased the impact strength from 20kG.cm to 52.5 kG.cm (increased by 162.5%). Adding the content of 2 wt% m-NS (m-NS-2) improved the impact strength of epoxy polymer film Epon 1001X75/Epi3125/m-NS-2 from 20 kG.cm to 55 kG.cm (increased by 175%). The glass transition temperature (Tg) of epoxy polymer composites Epon 1001X75/Epi3125, Epon 1001X75/Epi3125/NS-1, and Epon 1001X75/Epi3125/m-NS-2 gradually increased by 48 °C, 75 °C, and 79 °C. The obtained results showed that m-NS with KH-792 increased the mechanical properties of epoxy polymer film Epon 1001X75/Epi3125.

1. Introduction
After curing, epoxy resin has advantages such as corrosion resistance, heat resistance, and good adhesion, so it is used as a protective coating for steel structures, constructions, adhesives, and composite materials [1]. Besides the advantages, the epoxy resin also has the disadvantage of brittleness due to its chemical structure. There are many methods to improve the disadvantages of epoxy resin such as replacing different curing agents, modifying the main chain through reaction with the epoxy group, and using nanoparticles [2–12]. Studies have shown that, with appropriate nanoparticle content, the mechanical properties of epoxy resins are increased.

Silica SiO₂ is a very popular inorganic filler. Silica SiO₂ silica is non-toxic, stable, and highly heat resistant. Therefore, they are used as reinforcing fillers for plastics, polymers, rubber, coatings, and cosmetics. Due to the presence of hydroxyl groups (OH) on the surface, silica is strongly hydrophilic, easy to agglomerate, and difficult to disperse in the polymer matrix. The surface of the silica is modified with organic compounds to reduce the number of hydroxyl groups and increase the organic fraction. Therefore, the surface activity of modified silica changes from hydrophilic to hydrophobic [9, 13].
To increase surface activity as well as limit agglomeration, NS is often modified with silane compounds [5–7]. Nanocomposite based on Bisphenol-A epoxy resin (araldite® GY 6010) with 0–3 wt% NS Aerosil R200 treated with γ-aminopropyl triethoxy silane (amino A-100) increased mechanical properties and increased the Tg according to the content of NS [8].

Modification of NS by silane agents such as 3-aminopropyl triethoxy silane (KH-550), 3-glycidoxy propyl trimethoxy silane (KH-560), and 3-metacryloxy propyl trimethoxy silane (KH-570), used in synthesizing of poly (methyl methacrylate MMA–2-hydroxyethyl methacrylate HEMA), increased surface activity [9].

In research results [10–12], the authors studied the synthesis of NS nanoparticles from tetraethyl orthosilicate (TEOS) by sol gel method and modified NS particles by APTES (3-aminopropyltriethoxy silane) to determine the efficiency of the denaturation process and the content of 15.5 wt% APTES for the greatest grafting efficiency, the modified NS particles have uniform size and are smaller than the unmodified NS.

As a result of the study [14], the authors modified the surface of commercial NS particles (NS fumed S5502-Sigma) with 3-aminopropyltriethoxy silane (APTES) compound and achieved the highest grafting content of 15%. NS and m-NS with 1 wt% content significantly increased the impact strength of epoxy polymer film DER 671X75 cured by Epikure 3125.

In the study [15], the effects of silane coupling agents (KH-550, KH-560, KH-570, and KH-792) on the mechanical properties and thermal stability of cellulose were investigated with molecular dynamics simulation. It was found that the mechanical properties and thermal stability of cellulose can be improved by silane coupling agents. The simulation results showed that the mechanical parameters of cellulose are only slightly improved by KH-560 (γ-glycidyl ether oxypropyl trimethoxy silane) and KH-570 (γ-methacryloxy propyl trimethoxy silane) modified nano-SiO$_2$, while the mechanical parameters of cellulose are greatly improved by KH-550 (γ-aminopropyl triethoxy silane) and KH-792 (n-(2-aminooethyl)–3-aminopropyl trimethoxy silane) modified nano-SiO$_2$. Hydroxyl groups are produced after hydrolysis of the silane coupling agent. Therefore, the silane coupling agent can react with the silicon hydroxyl groups on the surface of nano-SiO$_2$, so that one end of the silane coupling agent can be connected with the surface of nano-SiO$_2$. The organic functional group of KH-550 is amino, the organic functional group of KH-560 is epoxy, the organic functional group of KH-570 is acyloxy, and the organic functional group of KH-792 is aminopropyl. Therefore, modifying cellulose with KH-792-modified nano-SiO$_2$ can significantly enhance mechanical properties and the thermal stability of cellulose.

The organic functional group of KH-792 is aminopropyl which has 03 active hydrogens and is strongly polar. Therefore, KH-792 is well compatible and reacts very easily with epoxy polymer.

In this study, the NS (fumed silica S5505) surface was modified by [3-(2-aminooethyl) aminopropyl] trimethoxy silane (KH-792) and determined the efficiency of KH-792 grafting on NS. The effect of modified NS on the mechanical properties of epoxy polymer film Epon 1001X75/Epikure 3125 was also studied.

2. Materials and methods

2.1. Materials

Epoxy resin Epon 1001X75 and hardener Epikure 3125 were purchased from Hexion. Epoxy resin Epon 1001X75 is a low color with 75% solids solution of epoxy resin in xylene, with an epoxy equivalent weight (EEW) of 450–500 g eq$^{-1}$. Epoxy resin Epon 1001X75 offers very good chemical and corrosion resistance. Epoxy resin Epon 1001X75 is used in industrial maintenance coatings including clear coats, primers, masonry surfaces, gloss, and semigloss enamels. Epikure 3125 hardener is a medium viscosity reactive polyamide curing agent with an amine number of 330–360 mg KOH g$^{-1}$. NS (fumed silica S5505-Sigma) is a white powder with an average particle size of 200–300 nm. [3-(2-Aminoethyl) aminopropyl] trimethoxy silane (KH-792) (China). Ethanol water with a concentration of 95° (v/v) (Chemsol-Vietnam). HCl (37%). Xylene, acetone (China).

2.2. Methods

2.2.1. Modification of NS surface by silane coupling agent

As a result of the study [14], the authors modified the surface of commercial NS particles (NS fumed S5502-Sigma) with 3-aminopropyltriethoxy silane (APTES) compound and achieved the highest grafting content of 15%. Therefore, the studied contents of KH-792/NS SiO$_2$ were selected as 15 wt%, 20 wt%, and 25 wt%.

Modification of NS surface by KH-792 silane compound through two stages. The first stage is the hydrolysis of KH-792 with ethanol with a concentration of 95° (v/v) or more. The second stage is the condensation of OH groups. The chemical reaction of the denaturation process is shown in figure 1.

In stage 1: The silane coupling agent KH-792 is hydrolyzed in ethanol water at pH 3–4 to form hydroxyl groups in the chain. Stage 2: Condensation of the hydroxylated silane KH-792 with NS. The reaction occurs when the hydroxyl groups (–OH) on the surface of the silica react with the formed hydroxyl groups (–OH) in stage 1 of KH-792.
To modify NS with KH-792, an appropriate ratio between KH-792 and ethanol is required. Weigh the amount of KH-792 and ethanol water into a 250 ml beaker at the volume ratio KH-792/ethanol water = 1/10 (v/v) (an excess of ethanol water is used to react the silane agent KH-792 completely), stirring gently at a speed of 100 rpm. It is necessary to add a small amount of 37% HCl solution so that the pH of the mixture reaches 3–4 (yellow orange). Hydrolysis reaction temperature will be maintained at 70 °C for 3 h. Next, by adding NS into the reaction mixture, the reaction temperature is still maintained at 70 °C, and the stirring speed will be raised to 200 rpm for 3 h. The mixture is then stabilized for 24 h before vacuum filtration and washed several times with ethanol water to remove excess KH-792. The obtained yellow white powder after vacuum extraction is modified NS. The obtained powder will be vacuum dried at 80 °C for 4 h.

2.2.2. Dispersion of NS and m-NS into epoxy resin EPON 1001X75
NS and m-NS were dispersed into epoxy resin EPON 1001X75 by mechanical stirring and ultrasonic vibration. Weigh the amount of NS/m-NS into a 250 ml beaker. Add acetone solvent to wet the NS/m-NS. The epoxy resin EPON 1001X75 was slowly added to the mixture and gradually increased the stirring speed to 1000 rpm, maintained for 30 min, increased the stirring speed to 1800 rpm, and maintained for 90 min. Next, the mixture was sonicated for 45 min.

2.2.3. Effect of NS and modified NS on the mechanical properties of epoxy polymer film
The contents of m-NS into epoxy resin Epon 1001X75 were 1 wt%, 2 wt%, 3 wt%, and 4 wt%. The content of NS in epoxy resin Epon 1001X75 was 1 wt%. Epikure 3125 polyamide curing agent was used with a content of 35 wt%. Sample symbols and components are described in table 1:

![Figure 1. Modification of NS by KH-792.](image-url)
2.3. Preparation samples and analytical methods
Epoxy resin Epon 1001X75 was cured by hardener Epikure 3125 with a mass ratio of 100/35 (wt/wt), determined by the method of determining the gel fraction in the Soxhlet kit. Epoxy polymer film coated on steel, fully cured for a minimum of 48 h before analysis. Evaluation of modifying and grafting of silane KH-792 into NS by FTIR spectroscopy on Bruker Instrument Model Tensor 37. A mechanical stirrer (model IKA-RW 20, Germany) and ultrasonic device Sonic Vibram cell (model CV334, USA) were used to study the dispersion of NS and m-NS into epoxy resin. SEM images were taken on Jeol machine (model JSM-IT 200) and Hitachi S4800, Japan. TEM images were taken on a Jeol machine (model JEM 1400, Japan). Thermo Gravimetric Analysis (TGA) was tested on Setaram Labsys Evo (TG-DSC 1600 °C) machine. Dynamic Mechanical Analysis was tested on DMA machine Q800 (TA Instruments).

2.4. Method to determine the mechanical properties of epoxy polymer film
Mechanical properties of epoxy polymer films are determined based on ISO, ASTM, JIS, and TCVN standards such as the flexibility (according to standard ISO 1519:2002, Erichsen equipment, model 266), the impact strength (standard ISO 6272:2002, Erichsen equipment, model 304), the adhesion (standard ASTM D3359–93, Erichsen equipment, model 295), the pencil hardness (standard JIS K5400–90) and the dry film thickness (Vietnam National Standard TCVN 9406: 2012, MiniTest 3100).

3. Results and discussion
3.1. Infrared spectra of NS and m-NS
The FTIR spectrum of NS is presented in figure 2.

On the infrared spectrum (figure 2), there were peaks showing the characteristic wave numbers of the bonding in silica SiO₂. The strong absorption band at the peak of 3429.63 cm⁻¹ is typical for the valence vibration of the O–H bonding in the water molecule. Besides, the absorption peak at 1631.20 cm⁻¹ is also characterized by the deformation fluctuations of the O–H group in the water molecule adsorbed on the surface of the material. The strong adsorption peaks on the infrared spectrum also show the characteristic Si–O bonding in the molecule. The two strong peaks at 1099.14 cm⁻¹ and 806.35 cm⁻¹ characterize the asymmetric and asymmetric valence vibrations of the Si–O bonding in the molecule. The strong peak at wave number 466.97 cm⁻¹ is typical for the strain oscillation of the Si–O bonding.

The FTIR spectrum of silane KH-792 is shown in figure 3.

From figure 3, it can be seen that the FTIR spectrum of silane KH-792 has peaks at wave numbers 3 341.99 cm⁻¹ and 3297.58 cm⁻¹, which is typical for the OH group. The peaks at 2942.95 cm⁻¹ and 2888.13 cm⁻¹ characterize the valence fluctuations of the Csp3H group. The peak at 1573.91 cm⁻¹ is typical for primary amine group fluctuations. The peak at 1489.46 cm⁻¹ characterizes the deformation vibration of the Csp3H

Figure 2. FTIR spectrum of NS.
The peaks at wave numbers 1034.79 cm$^{-1}$ and 788.05 cm$^{-1}$ are characteristic of valence fluctuations of the Si–O group. The peak at wave number 924.22 cm$^{-1}$ is characteristic of the vibration of the Si-OH bonding.

The FTIR spectrum of NS modified by silane KH-792 is presented as follows in figure 4:

Comparing the FTIR spectra of the NS and the FTIR spectra of m-NS (figures 2–4), the FTIR spectrum of m-NS also appears to have characteristic peaks for the OH and Si–O groups in the NS (peaks at 3436.97 cm$^{-1}$ and 1121.82 cm$^{-1}$). On the FTIR spectrum of m-NS, there are also similar peaks for the organic functional group on the FTIR spectrum of KH-792 such as the peak at 1630 cm$^{-1}$ which is typical for the deformation fluctuations of the amine group. The peak at 1630.69 cm$^{-1}$ and 3031.74 cm$^{-1}$ are typical for the valence oscillation of the C$_{sp3}$H group. The peaks at 1121.82 cm$^{-1}$ and 810.7 cm$^{-1}$ are characteristic of symmetric and asymmetrical vibration of Si–O–Si bonding, and the peak at 471.74 cm$^{-1}$ is typical for the bending vibration of O–Si–O bonding.

From the above FTIR data analysis results, it was shown that KH-792 was grafted on the NS surface by the qualitative method. In addition, the TGA method below was used to determine the amount of KH-792 that was grafted on the NS surface (figure 5).
3.2. Efficiency of NS modification by silane KH-792

Using the TGA method to determine the efficiency of NS modification by KH-792. The TGA curves of NS and m-NS are presented in figure 5 below:

Figure 5. TGA curves of NS and m-NS silane KH-792.

Table 2. The TGA results of NS and m-NS samples.

| Sample                  | Loss mass (wt%) |
|-------------------------|-----------------|
|                         | 300 °C | 315 °C | 400 °C | 500 °C | 600 °C | 700 °C | 800 °C |
| NS                      | 0.2    | 0.2    | 0.2    | 0.2    | 0.2    | 0.2    | 0.2    |
| m-NS-15% silane KH 792  | 11.7   | 11.46  | 12.63  | 12.64  | 12.67  | 12.67  | 12.66  |
| m-NS-20% silane KH 792  | 13.05  | 14.23  | 16.83  | 16.84  | 16.85  | 16.85  | 16.85  |
| m-NS-25% silane KH 792  | 12.5   | 12.56  | 15.63  | 15.67  | 15.67  | 15.67  | 15.66  |

3.2. Efficiency of NS modification by silane KH-792

Using the TGA method to determine the efficiency of NS modification by KH-792. The TGA curves of NS and m-NS are presented in figure 5 below:

Figure 5 shows that NS starts to decompose at 100 °C. This is the temperature representing the evaporation of water on the surface of silica SiO₂. However, the amount of water on the silica surface is very low (about 0.2 wt%). The residual mass of the SiO₂ sample is 99.8 wt%. Silica SiO₂ consists of siloxane bonding (Si–O–Si) which is very heat stable. On the silica surface adsorbs water to form hydroxyl groups (–OH). Therefore, thermal decomposition occurs only for the hydroxyl groups on the silica surface.

The m-NS samples begin to decompose at about 50 °C. Determine the content of KH-792 grafted into NS by subtracting the loss mass of the m-NS sample from the loss of the original NS sample at a temperature of 300 °C (because this is the temperature range before decomposition of the organic silane compounds – 315 °C) [11, 12, 14].

The loss mass (wt%) of m-NS and NS samples that decompose according to temperature are presented in table 2:

The TGA results in figure 5 and table 2 show that NS lost 0.2 wt%, this loss is the evaporation of the water on the silica surface. NS is modified with organic silane, so it has a low decomposition starting temperature of 50 °C. The m-NS-20 wt% silane KH 792 has the highest loss mass (wt%), corresponding to the largest grafting content of silane KH-792. Sample m-NS-20% silane KH-792 has a loss mass loss of 13.05 wt% at a decomposition temperature of 300 °C. At a decomposition temperature of 315 °C, the loss mass of sample m-NS-20% silane KH-792 is 14.23 wt%. From a temperature of 400 °C, the m-NS – 20 wt% KH 792 sample lost 16.85 wt%. Thus, the TGA results showed that the best content of silane KH-792 modified into NS was 20 wt%. 

Table 2. The TGA results of NS and m-NS samples.
3.3. Effects of NS and m-NS on mechanical properties of epoxy polymer film Epon 1001X75/Epi3125

3.3.1. Disperse NS and m-NS into epoxy resin

The NS and m-NS-20 wt% silane KH-792 were dispersed into the epoxy resin Epon 1001X75 by mechanical stirring and ultrasonic vibration. The investigated contents of the dispersion method were 1 wt% NS and 1 wt% m-NS. SEM images of NS and m-NS-20 wt% silane KH-792 were presented in figure 6. TEM images of epoxy nanocomposite Epon 1001X75/Epi3125/NS-1 and Epon 1001X75/Epi3125/m-NS-1 were presented in figure 7:

NS (fumed silica S5502) SiO₂ is a white powder with an average particle size of 200–300 nm. SEM images from figure 6(a) show that NS SiO₂ forms into granular clusters and tends to agglomerate due to surface activity and water absorption capacity. The SEM images from figure 6(b) show that the m-NS-20% silane KH 792 sample has a more uniform surface than the unmodified NS sample (figure 6(a)). NS is modified with silane to reduce the hydrophilicity of silica, increase hydrophobicity, reduce agglomeration, and easily disperse into polymers.

TEM images from figure 7(a) show that silica nanoparticles with a content of 1 wt% are well dispersed and form epoxy nanocomposite material Epon 1001X75/Epi3125/NS-1. However, silica particles tend to agglomerate into large clusters with an average particle size of 100–150 nm. This result is also similar to other studies [7, 9, 14]. TEM images from figure 7(b) show that m-NS-20% silane KH-792 with the content of 1 wt%
disperses well into epoxy resin Epon 1001X75 and forms epoxy nanocomposite material Epon 1001X75/ Epi3125/m-NS-1. Figure 7(b) also shows that the m-NS silane KH-792 particles have more uniform dispersion in the epoxy resin and reduce the agglomeration than the unmodified nanoparticle (figure 7(a)), with an average particle size of less than 100 nm. Figure 7(b) also shows that epoxy nanocomposite Epon 1001X75/Epi3125/m-NS-1 has a more uniformly distributed surface structure morphology than epoxy composite Epon 1001X75/ Epi3125/NS-1. The m-NS is more uniformly distributed than NS, reducing surface shrinkage during surface modification.

On the surface of silica, there are hydroxyl groups (–OH) that make silica strongly hydrophilic. Due to its strong hydrophilicity, silica particles are easy to agglomerate and difficult to disperse in the polymer matrix. Modification of silica surface by organic compounds to reduce hydroxyl group content, increase organic fraction, and change silica surface activity from hydrophilic to hydrophobic [9]. The silane compounds bind to the silica SiO₂ surface by organic and polymers, increasing dispersibility and better stability into organic solvents and polymers [13].

3.3.2. Mechanical properties of epoxy polymer films
Effects of NS and m-NS on the mechanical properties of epoxy polymer film Epon 1001X75/Epicure 3125 are presented in table 3:

The results from table 3 show that the epoxy polymer film Epon 1001X75/Epi3125 has a low impact strength of only 20 kG.cm. Due to the chemical structure of many aromatic rings, epoxy resins are very hard and brittle [1, 14, 16]. NS particles significantly improved the impact strength of epoxy resin Epon 1001X75, which increased the impact strength of epoxy polymer film Epon 1001X75/Epi3125/NS-1 from 20 kG.cm to 52.5 kG.cm (increased by 162.5%). The m-NS-20 wt% silane KH-792 significantly improves the mechanical properties of epoxy polymer films, in which the content of 2 wt% m-NS improves the impact strength of epoxy polymer Epon 1001X75/Epi3125/m-NS-2 from 20 kG.cm to 55 kG.cm (increased by 175%) and increase the pencil hardness from 5H to 7H.

Epoxy composite Epon 1001X75/Epi3125/NS-1, the impact strength is greatly improved. The content of the epoxy resin and m-NS must be suitable, of which content 2 wt% m-NS is best for epoxy resin Epon1001X75/Epi3125. Modifying NS particles with silane compounds increases the surface activity with the epoxy group and improves the mechanical properties of an epoxy polymer film.

The reaction between the epoxy resin and the m-NS silane particles is shown in figure 8.

The modification of the NS particles by a silane compound reduces the surface activity of the NS particles. The primary amine group on the surface of m-NS particles has very good activity when forming bonds with epoxy groups in epoxy resins, increasing the adhesion of polymeric coating films.

3.3.3. Dynamic Mechanical Analysis (DMA) of epoxy polymer composites
The results of DMA analysis of epoxy polymer composites samples Epon 1001X75/Epi3125 are presented in figures 9–11 below:

The DMA analysis recorded the variation in Storage Modulus, Loss Modulus, and Tan Delta (tan delta is the value of the ratio between the loss modulus and the storage modulus) of the polymer sample with temperature. The glass transition temperature (Tg) was determined at the maximum point of the Tan delta value.

The Tg of epoxy polymer composite samples Epon 1001X75/Epi3125 from DMA analysis are described in table 4:

The results from table 4 show that the Tg of the epoxy composite polymer samples Epon 1001X75/Epi3125, Epoxy Epon 1001X75/Epi3125/NS-1, and Epoxy Epon 1001X75/Epi3125/m-NS-2 gradually increased to 48 °C, 75 °C, and 79 °C. The Tg of polymer materials depends on many factors such as crosslinking density, composition and structure of polymer chains, fillers, nanoparticles, etc. Epoxy polymer Epon 1001X75 cures with polyamide curing agent Epikure 3125 (Epoxy Epon 1001X75/Epi3125) has no fillers, so the lowest Tg is 48 °C. Nanocomposite materials and nanoparticles are both fillers and increase the bonding ability between the matrix resin and the curing agent. NS with the content of 1 wt% increases the bonding degree and reduces the load on epoxy polymer Epon 1001X75/Epi3125/NS-1, so the Tg increases to 75 °C. The m-NS with the content of 2 wt% (m-NS-2) increases the surface activity in epoxy polymer and increases the ability to further bonding between the base resin and the curing agent, so Tg increases to 79 °C. The Tg also adds to the explanation of the impact strength of the samples in table 3 above.

4. Conclusions
In this study, NS was modified with the content of 20 wt% silane KH –792 for the highest denaturation efficiency. NS and m-NS were well dispersed into epoxy resin Epon 1001X75 by mechanical and ultrasonic
Table 3. The mechanical properties of epoxy polymer films Epon 1001X75/Epi 3125/m-NS.

| Polymer                  | Dry film thickness (μm) | Flexibility (mm) | Pencil hardness | Impact strength (kG.cm) | Adhesion |
|--------------------------|-------------------------|------------------|-----------------|--------------------------|----------|
| Epoxy Epon 1001X75/Epi3125 | 51.32                   | 2                | 5H              | 20                       | 5B       |
| Epoxy Epoxy 1001X75/Epi3125/NS-1 | 52.58             | 2                | 6H              | 52.5                     | 5B       |
| Epoxy Epoxy 1001X75/Epi3125/m-NS-1 | 52.66            | 2                | 7H              | 52.5                     | 5B       |
| Epoxy Epoxy 1001X75/Epi3125/m-NS-2 | 51.18             | 2                | 7H              | 55                       | 5B       |
| Epoxy Epoxy 1001X75/Epi3125/m-NS-3 | 53.06             | 2                | 4H              | 40                       | 4B       |
| Epoxy Epoxy 1001X75/Epi3125/m-NS-4 | 51.1              | 2                | 3H              | 35                       | 3B       |
Figure 8. The reaction between epoxy resin and m-NS silane KH-792.

![Chemical reaction between epoxy resin and m-NS silane KH-792](image)

Figure 9. DMA curve of epoxy composite Epon 1001X75/Epi3125.

![DMA curve of epoxy composite Epon 1001X75/Epi3125](image)

Figure 10. DMA curve of epoxy composite Epon 1001X75/Epi3125/NS-1.

![DMA curve of epoxy composite Epon 1001X75/Epi3125/NS-1](image)
stirring. The mechanical properties of epoxy polymer film Epon 1001X75/Epi3125/NS-1 increased the impact strength by 162.5% with the content of 1 wt% NS. The mechanical of epoxy polymer film Epon 1001X75/Epi3125/m-NS-2 increased the impact strength by 175% with the content of 2 wt% m-NS-2 and increased the pencil hardness of the film from 5H to 7H. The glass transition temperature (Tg) of epoxy polymer composites Epon 1001X75/Epi3125, Epon 1001X75/Epi3125/NS-1, and Epon 1001X75/Epi3125/m-NS-2 gradually increased by 48 °C, 75 °C, and 79 °C. The obtained results showed that modified NS KH-792 increased the mechanical properties of epoxy polymer film Epon 1001X75/Epi3125.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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