Volume 8, Issue 2, pp. 23-28, 2024.

International Journal of Scientific Engineering and Science
ISSN (Online): 2456-7361

Hardness Analysis of Composite Materials Based on Epoxy Resin and Graphene

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Abstract*-One material that is currently being developed is graphene. To determine the hardness value of graphene-based composite materials with 0.34% and 0.70% graphene composition. This type of research uses experimental methods, which is a way to find the hardness strength of graphene-based composite materials. From the results of hardness testing, the hardness level of graphene-based composite materials with a 0.34% graphene composition has an average hardness value of 766.88 HL while a 0.70% graphene composition has an average hardness value of 794.76 HL. It can be concluded from this research that the difference in the level of hardness of materials made from 0.34% and 0.70% graphene has a percentage difference of 3.5% with the hardness value of the 0.34% graphene composition being lower than the hardness value of the 0.70% graphene composition.*

Keywords*-Composite Materials, Graphene, Leeb Tester Hardness.*

I. INTRODUCTION

Industry needs materials to make a design. In industry, materials play an important role with techniques for extracting materials and transforming them into useful structures. So that materials are arranged or made from a material, it can be concluded that materials are several materials that are used to make a product or finished goods that are more useful (William D. Callister & Rethwisch, 2009).

Materials can be categorized in various ways, one of which is based on atomic bonds and structure. Based on these categories, materials can be classified into metal, polymer and ceramic materials. Apart from that, there are two groups of materials that are quite important in materials engineering, one of which is composites (Sari, 2018).

Composite is a new type of engineered material consisting of two or more materials where the properties of each material are different from each other, both chemical and physical, and remain separate in the final result of the material (composite material). Due to the differences in the constituent materials, the composite between the materials must bond strongly, so it is necessary to add a wetting agent (Nayiroh, 2013).

Composite materials generally use epoxy resin and matrix. Epoxy resin is a product produced by the reaction of base materials and hardeners, as well as filler materials, which can be used as insulating material for electrical equipment. Its properties vary depending on the type, conditions, and mixing with the hardener. The advantage of epoxy resin is that it has stability under unfavourable conditions, so it is very good at increasing the reliability of electrical equipment. Apart from that, epoxy resin has perfect dielectric and good mechanical properties (Heri et al., 2012).

One material that is currently being developed is graphene. Graphene is one of the carbon family of elements, which (Geim & Novoselov, 2007) in 2004. Physicists, chemists and materials scientists have now focused on the applications of graphene for several fields of research and industry because it has excellent properties including high electron mobility (~10,000 $cm^2/V•s$), Quantum effects Hall at room temperature, good optical transparency (97.7%), large specific surface area (2630 m^2/g), high Young's modulus (~1 TPa), and high thermal conductivity (~3000 W/m•K) (Suwandana & Susanti, 2015). Graphene is the strongest material discovered in 2010. It is known that graphene is 200 times stronger than steel and 1,000 times lighter than paper. Graphene is made of just one layer of carbon atoms positioned in a triangular lattice. This material is expected to have a major impact on the aerospace industry and automobile production. Some people believe that in the next few years, cars, planes and many electronics will use graphene based technology (Kristina, 2021).

One example of the application of this Epoxy Resin and Graphene composite is in making bulletproof vests. The use of graphene as a protective material can be done by making composites (Hussain, 2006). It is well known that graphene has a Young's modulus and tensile strength above 1 Tera pascal (Fischer, 2003). One of the promising materials for manufacturing ultra-strong polymer composites due to its extraordinary mechanical properties is graphene (Bernholc, 2002).

Hardness is one method for determining the mechanical properties of a material. Hardness is not a physical constant, its value not only depends on the material being tested, but is also influenced by the test method. If the test method used is different, the results of the mechanical properties will also be different (Verdins G. D Kanaska & Kleinberg's, 2013). For this reason, it is necessary to conduct tests on composite hardness to support the use of graphene composites for uses in other sectors.

II. THEORITICAL REVIEW

1. *Composite*

The emergence of composites as a distinct classification of materials began in the mid-20th century with the creation of purposely designed and engineered multiphase composites such as fiberglass-reinforced polymers (Callister Jr. &

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Volume 8, Issue 2, pp. 23-28, 2024. ISSN (Online): 2456-7361

Rethwisch, 2009). Although multiphase materials, such as wood, bricks made of clay reinforced with straw, shells, and even alloys such as steel have been known for thousands of years, the introduction of new concepts for combining different materials during manufacture led to the identification of composites as a new class that stands apart from the familiar metals, ceramics and polymers. We now realize that this multiphase composite concept provides an exciting opportunity to design a very large variety of materials with combinations of properties that cannot be met by any monolithic conventional alloy of metals, ceramics, and polymer materials.

A composite is a material formed from a combination of two or more materials that have stronger mechanical properties than the materials from which they are made. Composites consist of two parts, namely the matrix as the binder or protector of the composite and the filler as the composite filler. Natural fibers are an alternative composite filler for various polymer composites because of their superiority over synthetic fibers. Natural fibers are easy to obtain at low prices, easy to process, low density, environmentally friendly, and biodegradable (Kusumastuti, 2009).

Composites consist of two (or more) individual materials, which come from previously discussed categories such as metals, ceramics, and polymers. The goal of composite design is to achieve a combination of properties not displayed by a single material, and also to incorporate the best characteristics of each component material. A large number of types of compost are represented by a combination of metals, ceramics and polymers. Furthermore, some natural materials are composites for example, wood and bone. However, most of them are synthetic (or man-made) composites (William D. Callister & Rethwisch, 2009).

Materials that have special and unusual properties are required for a number of high-tech applications such as those found in the aerospace, underwater, biotechnology, and transportation industries. For example, aircraft engineers are increasingly looking for low-density structural materials; strong, rigid, and resistant to abrasion and impact; and does not corrode easily. This is a rather formidable combination of characteristics. Among monolithic materials, strong materials are relatively dense; increasing strength or stiffness generally results in a decrease in toughness. The combination and range of material properties has been, and is still being expanded by the development of composite materials. In general, composites are considered to be multiphase materials that exhibit a significant proportion of the properties of both constituent phases so that a better combination of properties is realized. According to this principle of combined action, a better combination of properties is formed by a judicious combination of two or more different materials. Property swaps are also made for many composites (Chawla, 2012).

Types of composites have been discussed namely; multiphase metal alloys, ceramics, and polymers. For example, pearlite steel has a microstructure consisting of alternating layers of ferrite and cementite. The ferrite phase is soft and ductile, while the cementite is hard and very brittle. The combined mechanical characteristics of pearlite (quite high ductility and strength) are superior to those of either of its constituent phases. A number of composites also occur in nature. For example, wood consists of strong, flexible cellulose fibers surrounded and held together by a stiffer material called lignin. In addition, bones are a composite of the strong but soft protein collagen and hard and brittle minerals, apatite. Composites, in the present context, are multiphase materials that are created artificially, as opposed to those that occur or form naturally. In addition, the constituent phases must be chemically different and separated by different interfaces (Chawla, 2012).

In designing composite materials, scientists and engineers cleverly combine various metals, ceramics and polymers to produce a new generation of extraordinary materials. Most composites have been created to improve a combination of mechanical characteristics such as stiffness, toughness, strength and high temperature. Many composite materials consist of only two phases; one is called the matrix, which is continuous and surrounds the other phase, often called the dispersed phase. Composite properties are a function of the properties of the constituent phases, their relative amounts, and the geometry of the dispersed phase. Dispersed phase geometry in this context means particle shape and particle size, distribution, and orientation. One simple scheme for the classification of composite materials, consisting of three main divisions: particle-reinforced, fiber-reinforced and structural composites; also, there are at least two subdivisions for each.

The dispersed phase for particle-reinforced composites is the same (i.e., the particle dimensions are approximately the same in all directions); for fiber-reinforced composites, the dispersed phase has fiber geometry (i.e., a large length-to-diameter ratio). Structural composites are a combination of composites and homogeneous materials (Chawla, 2012).

2. Graphene

Graphene is the name given to a flat monolayer of solid carbon atoms packed into a two-dimensional (2D) honeycomb lattice, and is the basic building block for graphite materials of all other dimensions. It can be wrapped into OD fullerene, rolled into 1D nano tubes or stacked into 3D graphite. Theoretically, graphene (or '2D graphite') has been studied for sixty years, and is widely used to describe the properties of various carbon-based materials. Forty years later, it was realized that graphene also provided an excellent condensed matter analogue of (2+1-dimensional quantum electrodynamics), which propelled graphene into a rapidly developing theoretical toy model.

On the other hand, although known as an integral part of 3D materials, graphene is considered not to exist in a free state, is described as an academic material and is believed to be unstable with respect to the formation of curved structures such as soot, fullerenes and nanotubes. Suddenly, the vintage model turned into reality, when freestanding graphene was unexpectedly discovered three years ago and especially when follow-up experiments confirmed that its charge carriers were indeed massless Dirac fermions. So, the graphene 'gold rush' has begun (Gem & Novoselov, 2007).

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International Journal of Scientific Engineering and Science
Volume 8, Issue 2, pp. 23-28, 2024. ISSN (Online): 2456-7361

3. Epoxy Resin

The definition of resin according to the Big Indonesian Dictionary is a formless solid substance, yellow-brown in color, derived from the sap of the resin tree as a material for making varnish, glue, solder, and so on (Asmi et al., 2019). In the industrial or construction world, the use of resin is very popular. Even in making handicrafts, resin is often used. Resin itself is a material made from natural ingredients and chemical compounds. Initially, resin was made from natural ingredients, namely the sap of various trees such as gooseberry or conifer. However, Because it has raw materials from natural ingredients. Resin it self is divided into several types, namely, Vinyl Ester resin, Polyester resin, Upcast resin, Acrylic resin, Phenolic resin, Polyethylene resin, Polystyrene resin, Polyamide resin, and finally Epoxy resin. (Rifda, 2021) used in this research.

III. METHOD

This research is experimental research, namely a way to find hardness in graphene based composite materials.

This research design uses standard Leeb Tester Hardness test specimens with dimensions of 5 cm x 5 cm x 1 cm

The research variable is an added ingredient in making graphene-based composite materials, namely the difference in the percentage of graphene and matrix used as test specimens in a design. Therefore, the two sample groups in this study are given the following symbols:

1. X1 = Hardness value graphene composite material with a graphene percentage of 0.34% and 98.66% resin + 1% catalyst (X1)
2. X2 = Hardness value graphene composite material with a graphene percentage of 0.70% and 98.30% resin + 1% catalyst (X2)

The data collection technique used in this research is by conducting experiments on making graphene-based composite materials with different percentages, and hardness test specimens will be made.

After its formation, each test specimen was weighed to determine the density of each material, and tested using the Leeb Hardness Tester at the Makassar State University Laboratory.

The data taken from this hardness test is the average hardness of each specimen which is then compared to the hardness of different types of added material, using the percentage method, so that the research results can be seen which type of material has better hardness.

IV. RESULTS AND DISCUSSION

The research was carried out using a type of test, namely the Leeb Tester Hardness test. The data obtained from the research results are the results of experiments carried out at the Mechanical Engineering Materials Testing Laboratory, Makassar State University. The materials used in this research are epoxy resin and graphene.

In this section, we will describe the results of research data processing from the results of the Leeb Tester Hardness hardness test which consists of 3 specimens, namely normal specimens containing only epoxy resin, 0.34% specimens containing epoxy resin and graphene with a composition of 0.34% and specimens 0.70% containing epoxy resin and graphene with a composition of 0.70%. The description of the data is as follows:

A. Research result

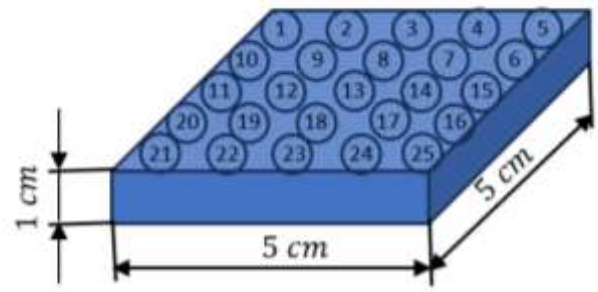

Fig. 1. Test Impact Point Hardness
(Testing Technique)

Source: Primary Data 2023

1. Normal Specimen

TABLE 1. Leeb Tester Hardness Test Results Normal Specimen

Composite volume fraction			Hardness Test Results (HL) (Testing)					Strength Average
Catalyst (%)	Matrix (Epoxy)	Filler (Graphene)	1-5	6-10	11-15	16-20	21-25	
(1%)	(99%)	(0%)	764.4	751	754	736.2	773.6	755.84

Source: Primary Data 2023

From table 1 it can be seen that there were 25 Leeb Tester Hardness tests carried out at 25 points which were carried out sequentially in 5 rows and then the average value was drawn. Specimens 1-5 have an average test value of 764.4 HL, specimens 6-10 have an average test value of 751 HL, specimens 11-15 have a test value of 754 HL, specimens 16-20 have an average value of 736.2 HL, and specimens 21-25 had an average value of 773.6 HL. From the 5 average values for each series, it can be seen that the largest hardness value was obtained in the 5th series with a value of 773.6 HL, while the average value of the test from 25 points was 755.84 HL. The graph of the 5 series test results can be seen in Figure 2 below.

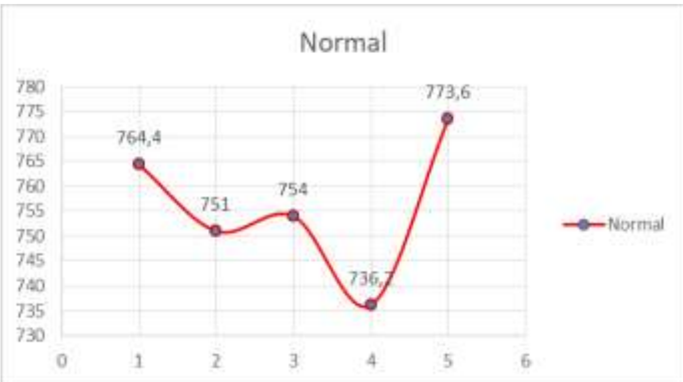

Fig. 2. Graph of Hardness Test Results *Leeb Hardness Tester* Normal Specimen

Source: Primary Data 2023

2. Graphene Specimen 0.34%

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International Journal of Scientific Engineering and Science
Volume 8, Issue 2, pp. 23-28, 2024. ISSN (Online): 2456-7361

TABLE 2. Hardness Test Results *Leeb Hardness Tester* Graphene Specimen 0.34%

Composite volume fraction			**Hardness Test Results (HL)** (Testing)					**Strength Average**
Catalyst (%)	Matrix (Epoxy)	Filler (Graphene)	1-5	6-10	11-15	16-20	21-25	
(1%)	(98.66%)	(0.34%)	769	754.6	770.8	773.8	766.2	766.88

Source: Primary Data 2023

From table 2 it can be seen that there were 25 Leeb Tester Hardness tests carried out at 25 points which were carried out sequentially in 5 rows and then the average value was drawn. Specimens 1-5 have an average test value of 769 HL, specimens 6-10 have an average test value of 754.6 HL, specimens 11-15 have a test value of 770.8 HL, specimens 16-20 have an average value of 773 .8 HL, and specimens 21-25 had an average value of 766.2 HL. From the 5 average values for each series, it can be seen that the largest hardness value was obtained in the 4th series with a value of 773.8 HL, while the average value of the test from 25 points was 766.88 HL. The graph of the 5 series test results can be seen in Figure 3 below.

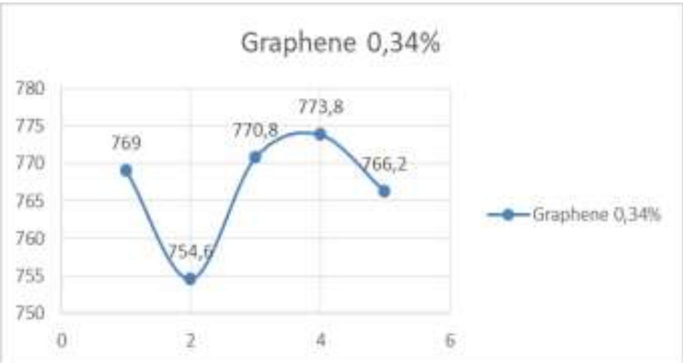

Fig. 3. Graph of Hardness Test Results *Leeb Hardness Tester* 1% Graphene Specimen
Source: Primary Data 2023

3. *Graphene Specimen 0.70%*

TABLE 3. Hardness Test Results *Leeb Hardness Tester* Graphene Specimen 0.70%

Composite volume fraction			**Hardness Test Results (HL)** (Testing)					**Strength Average**
Catalyst (%)	Matrix (Epoxy)	Filler (Graphene)	1-5	6-10	11-15	16-20	21-25	
(1%)	(98.30%)	(0.70%)	798.4	791.6	787.4	777.8	818.6	794.76

Source: Primary Data 2023

From table 3 it can be seen that there were 25 Leeb Tester Hardness tests carried out at 25 points which were carried out sequentially in 5 rows and then the average value was drawn. Specimens 1-5 have an average test value of 798.4 HL, specimens 6-10 have an average test value of 791.6 HL, specimens 11-15 have a test value of 787.4 HL, specimens 16-20 have an average value of the average was 777.8 HL, and specimens 21-25 had an average value of 818.6 HL. From the 5 average values for each series, it can be seen that the largest hardness value was obtained in the 5th series with a value of 818.6 HL, while the average test value from 25 points was 794.76 HL. The graph of the 5 series test results can be seen in Figure 4 below.

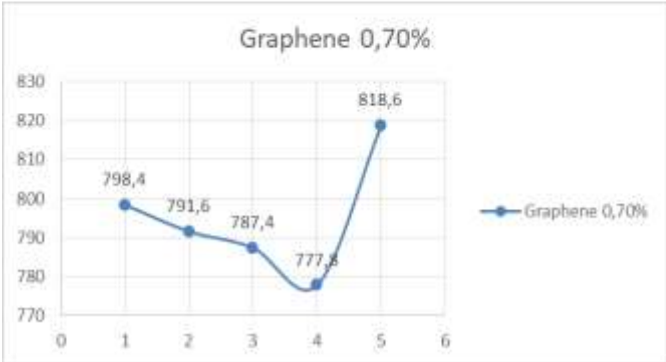

Fig. 4. Graph of Hardness Test Results *Leeb Hardness Tester* Graphene Specimen 0.70%
Source: Primary Data 2023

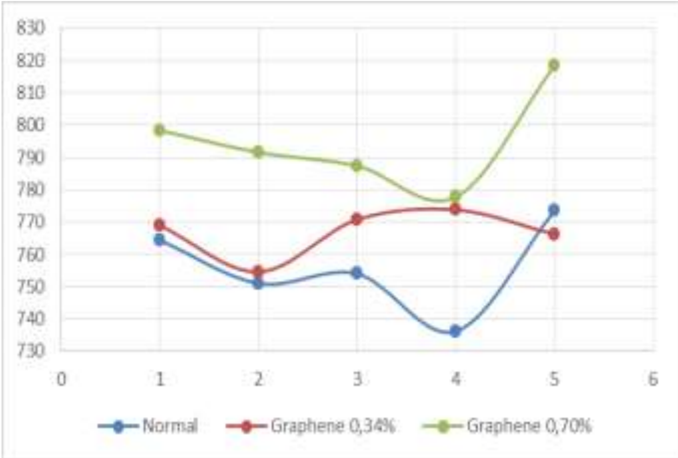

Fig. 5. Graph of Hardness Comparison *Leeb Hardness Tester* Each Specimen
Source: Primary Data 2023

From Figure 5 above, you can see a comparison of the hardness test results *Leeb Hardness Tester* For each specimen that has been tested for hardness, the Normal Sample is marked in blue with the highest value being 773.6 HL and the lowest value being 736.2 HL. The 0.34% Graphene sample is marked in maroon red with the highest value being 773.8 HL and the lowest value being 754.6 HL. And the 0.70% Graphene sample is marked in green with the highest value being 818.6 HL and the lowest value being 777.8 HL.

TABLE 4. Average Hardness Value *Leeb Hardness Tester* Each Specimen

No	**Specimen Type**		
	Normal	***Graphene*0.34%**	***Graphene*0.70%**
Average	755.84	766.88	794.76

Source: Primary Data 2023

From table 4 it can be seen that there are 3 types of specimens, each of which has been tested for Leeb Tester Hardness with 25 points carried out sequentially in 5 rows and then the average value is drawn. Each specimen has a different material composition and that is what makes the hardness value of each specimen different. The average value drawn in the test is that the normal specimen has an average

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value of 755.84 HL, the 0.34% graphene specimen has an average value of 766.88 HL, and the 0.70% graphene specimen has an average value of 794 .76 HL. It can be concluded that the highest average value is the 0.70% graphene specimen with a value of 794.76 HL.

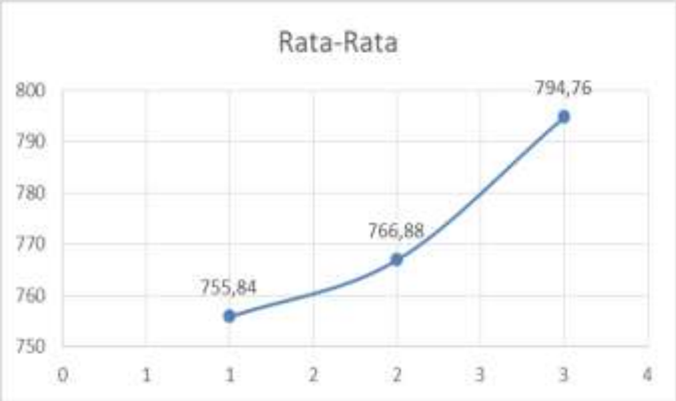

Fig. 6. Graph of Average Hardness Value *Leeb Hardness Tester* Each Specimen

Source: Primary Data 2023

B. *Discussion*

This research aims to determine the comparison of hardness in graphene composites with a graphene composition of 0.34% and 0.70% with the following explanation:

1. Graphene composite with a percentage of 0.34% gives better results regarding hardness values compared to normal specimens (only resin) with a difference of 1.4%. This is in accordance with research (Kristianta et al., 2017) which states that materials with the addition of powder elements in the composition of the composite that you want to make will increase the hardness value along with the percentage of powder added. This supports the initial theory which states that adding powder elements to fill the lattice that makes up a material will increase the hardness of the material. However, the hardness of the material is also influenced by the balanced composition that makes up the composite as explained by (Arif et al., 2019) based on the 4 different types of composition it consists of epoxy and variations in the percentage of matrix content in the composite are 30%, 35%, 40%, 45% and it is found that the 40% material is the material with the comparative composition which has the highest hardness when compared with the other 3 compositions, as well as the material with the composition Graphene 0.34% and 0.70% have different levels of hardness. The 0.34% graphene composite material has a relatively lower level of hardness compared to the 0.70% graphene composite material, although the reduction in hardness is not felt to be significant.
2. Graphene composites with a percentage of 0.70% provide better results regarding hardness values compared to specimens with a graphene percentage of 0.34% with a difference of 3.5%. This is in accordance with research (Setiadi & Sulardjaka, 2014) which states that the hardness of the AlSiMg composite will increase with increasing levels of 5% SiC addition with the highest hardness of 75.15 HRB. As is the case with composites with a graphene percentage of 0.70%, they have maximum strength with an average hardness value of 0.70%794.76 HL while the composite with a graphene composition of 0.34% has a lower hardness value with an average hardness value of 766.88 HL. However, the hardness of the material is also influenced by the balanced composition that makes up the composite as explained by (Sunardi et al., 2015) that the addition of a mixture of coal fly ash powder to the bamboo powder composite will affect the characteristics of the composite alternative brake lining material. Composite composition (K1) with a composition ratio of bamboo powder and coal fly ash powder (50:10%), (K2) with a composition ratio of (45:15%), and (K3) with a composition ratio of (40:20%). In hardness testing, the highest value was obtained for the composite (K3) with a hardness value of 51.67 N/mm^2. For composites (K2) it has a hardness value of 45.33 N/mm^2. The lowest hardness value in the composite (K1) has a hardness value of 39 N/mm^2. So, the more balanced the composite composition obtained, the higher the hardness value will be.

V. Conclusion

Based on the research results, data analysis and discussion, it can be concluded that:

1. The hardness level of the graphene-based composite material with a graphene composition variation of 0.34% has an average hardness value of 766.88 HL.
2. The hardness level of the graphene-based composite material with a graphene composition variation of 0.70% has an average hardness value of 794.76 HL.
3. The level of difference in the hardness of graphene-based materials with variations in graphene composition of 0.34% and 0.70% has a percentage difference of 3.5% with the hardness value of the graphene composition being 0.34% lower than the hardness value of the graphene composition of 0.70%.

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