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Article

Impact of Zirconium Carbide Particles on the Microstructure and Mechanical Characteristics of As-Cast and Heat Treated Al7475-Zirconim Carbide Composites

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Abstract: The aluminum alloys are prominently employed in the automotive, defense and aerospace industries owing to their excellent properties as compared to that of other metals and alloys. The present work has been centered on the synthesis and the evaluation of mechanical properties of cast and heat treated Al7475-Zirconium carbide composites. The composites were prepared by stir casting method. In order to enhance the properties, Al7475 alloy and Al7475-Zirconium carbide composite were subjected to a T6 heat treatment. The microstructural analysis and tensile, compression, impact and hardness tests were performed on the as-cast as well as T6 heat treated composite specimens. The microstructure of as-cast and heat treated Al7475-Zirconium carbide composite has revealed that the matrix of Al7475 alloy consisted of uniformly dispersed Zirconium carbide particles. The scanning electron microscopy image of heat-treated composite showed a decrease in grain size due to heat treatment effect, resulting in an increase in the strength of the composite. The mechanical properties of heat-treated Al7475-Zirconium carbide composite are superior compared to the as-cast composite. The ultimate tensile strength, yield strength, compression strength, impact strength and hardness of heat treated composite are 16.8%, 15.5%, 18.7%, 18.75% & 22.3% respectively higher than that of as-cast composite.

Keywords: Al7475; zirconium carbide; heat treatment; tensile strength; compression strength

1. Introduction

As the need for materials with several desirable properties increases, researchers are currently working on producing and evaluating new composite materials to meet the needs of the industrial

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industry. Composites are a mixture of materials that are made up of a matrix that contains micron-level and sub-micron-level dispersion of several different kinds of materials that are similar to one another. In most cases, the component that contributes to reinforcement is dispersed within matrix component [1]. Due to the fact that they possess high specific strength, stiffness, and heat resistance, metal matrix composites (MMCs) have recently garnered a significant amount of attention in different industrial sectors. These materials constitute a new category of industrial materials. The reinforcements are dispersed throughout the metal matrix throughout the manufacturing process. When the characteristics of the base metal are desired to be improved, reinforcements are typically used. Aluminum alloy-based MMCs are presently employed in many applications such as braking discs, cylinders, and pistons [2].

When it comes to resistance to fatigue crack propagation, aluminum 7475 is a material that offers strength and fracture toughness. Al7475 alloy is a perfect aircraft alloy, which is suitable for use in the construction of fuselage skins, bulkheads, and wing sections for commercial, fighter, and transport aircraft. A wide range of applications can benefit from the exceptional toughness offered by Aluminum Alloy 7475, which is produced from Aluminum 7075. Metalworking techniques like as machining, forging, and heat treatment are some of the choices that are available with this alloy [3]. The airframe and other aerospace assemblies are among the many applications that make extensive use of this material because of its high strength specifications. Al7050 aluminium alloys have a very good electrical conductivity, strong corrosion-resistance features, and are generally good at low temperatures.

Zirconium carbide is a high-performance ceramic material known for its exceptional properties. Its chemical formula is ZrC. It is having high melting point approximately 3,550°C (6,420°F), one of the highest among ceramics. ZrC is typically synthesized by reducing zirconium oxide (ZrO2) with carbon at high temperatures [4]. It has high hardness, making it very wear-resistant. It is stable at high temperatures and in various chemical environments. It has good thermal conductivity, suitable for high-temperature applications. It is used in applications such as aerospace, electronics industry, cutting tools and abrasives.

Liquid state techniques, semisolid techniques, and powder metallurgy procedures are the three production processes that are typically utilized when producing particulate reinforced MMCs. Ceramic particles are incorporated into a molten metallic matrix during the manufacturing of MMCs using liquid state techniques [5]. The material is then cast in molds during the casting process. As part of this particular research endeavor, the stir casting method is being applied. When it comes to the production of composite materials, stir casting is a procedure that makes use of a liquid condition. Utilizing a stirrer, this method involves combining molten metal with preheated reinforcing elements in order to complete the process. Once the mixing is complete, the liquid composite material is then cast in molds according to the desired forms. The most essential and extensively used casting alloys are those that are made of aluminum alloys. Moreover, one reason for the increasing use of cast alloys is the possibility of enhancing their mechanical properties through heat treatment [6].

There are a variety of heat treatments that have been standardized by aluminum associations. The application of these heat treatments in aluminium foundries is contingent upon the type of casting, alloy, and casting requirements. These heat treatments consist of distinct combinations of temperatures and periods. The standard T6 heat treatment is typically utilized in the manufacturing of components, and it is comprised of three stages: solution heat treating, quenching, and artificial aging [7]. Solution heat treating has two beneficial effects on cast aluminum alloy components. The first is an improvement in ductility, which is achieved by spheroidizing the eutectic silicon particulates in the microstructure. The second benefit is an improvement in the alloy's yield strength, which is accomplished through the development of a high number of fine precipitates that harden the soft aluminum matrix. For the purpose of determining how the mechanical characteristics of Aluminium alloys are affected by the temperature and duration of the solution, numerous investigations have been carried out [8]. Quenching, in contrast, is usually performed at ambient temperature to create a supersaturated solid solution consisting of solute atoms and vacancies. This is done to enhance the process of aging and increase its effectiveness. The best mechanical properties

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are achieved with the fastest rapid quench rate; however, this also has the potential to cause an unbearable amount of deformation or breaking in components. To summarize, the artificial ageing process entails subjecting the casting to further heating at relatively low temperatures. Precipitation of dissolved elements occurs during this period. The second factor involves improving the yield strength of the alloy by inducing the production of numerous small precipitates that reinforce the malleable aluminum matrix [9]. Because of these precipitates, the material is strengthened, which is a result of their presence.

A scan of literature survey has been carried out on the Microstructure Study and Mechanical Characteristics of as cast and heat treated Aluminum alloy particulate reinforced Composites and is discussed as follows.

Krishna Mohan Singh [10] et al. conducted a study on the production, analysis, and impact of heat treatment on the wear behaviour of aluminum MMCs reinforced with B4C. The Al7075/B4C composites that have undergone heat treatment exhibit greater hardness in comparison to the Al7075/B4C composites that have not been heat treated. B.M. Viswanatha1 [11] et al. investigate the influence of heat treatment on the microstructure of Al-7Si alloy based MMCs. Through the use of the stir-cast method, the composites that were established from the A356 basis were effectively manufactured. A significant improvement in the material's tensile and hardness features was achieved as a consequence of the heat treatment technique. An investigation on the impact of heat treatment has on the mechanical characteristics of AA2024 aluminum alloys that contain nanoparticles was carried out by Hamid M. Mahan [12] et al. It was discovered that the quick solidification process and thermal treatment contributed significantly to the improvement of a variety of mechanical properties and the reduction of microsegregation. Gurumurthy B. M. [13] et al. worked on the impact of heat treatment on the tensile characteristics of composites that were built of Al7075 alloy and white cast iron particles. Age hardening was applied to both the Al7075 alloy and the Al7075-WCI composites, which resulted in a significant improvement in the mechanical properties of both of these materials.

Raj Kumar [14] et al. worked on the Mechanical fractography and worn surface analysis were performed on composites composed of Al7075 alloy, nanographite, and ZrO2 particles. Within the matrix of the Al7075 alloy, the graphite and ZrO2 particles were distributed in a homogeneous manner. Composites have seen improvements in their hardness, impact strength, and tensile strength as a result of the introduction of dual reinforcing from the beginning. V. Bharath [15] et al. to investigate the microstructural characterization and tensile properties of composites that were composed of Al2014 alloy and Al2O3 particles. After the composite samples were subjected to heat treatment, it was found that the mechanical properties of both the Al2014 matrix alloy and the Al2014-15 % Al2O3 composite samples were greatly enhanced.

Shengqing Hu [16] et al. studied the effect of heat treatment on the mechanical properties of AlCoCrFeNi/A356 composites. By subjecting the AMCs to the most favorable conditions for solution treatment, it has been discovered that it is possible to achieve excellent mechanical characteristics. The purpose of the study that was carried out by Xin Li [17] and colleagues was to evaluate the influence that heat treatment has on the mechanical properties of a composite material that is composed of Al-Si-Cu-Mg aluminium alloy and SiC particles. After the T6 heat treatment procedure, it has been found that the UTS of the heat treated composites are more than those of the as-casts samples.

Gopal Krishna U B [18] et al. studied the synthesis and microstructure analysis of a composite material consisting of an Al7075 matrix and Micro WC-Co particles. The composite was produced using stir casting process. The SEM pictures showed a even dispersion of ceramic particles throughout the matrix. The EDX spectrum examination verifies the existence of elements such as Aluminum (Al), Cobalt (Co), Tungsten (W), Carbon (C), Zinc (Zn), Magnesium (Mg), and Manganese (Mn) in the composite. An investigation into the impact of heat treatment has on the mechanical properties of Al7075 based composites was carried out by Siddesh Matti [19] et al. There is a positive association between the proportion of reinforcements and the UTS and yield strength of composites made from Al7075 alloy steel, regardless of whether or not the reinforcements have been subjected

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to heat treatment. N. Ramadoss [20] et al. worked on the production of composites consisting of Al7075 alloy, B4C and BN particles using stir casting process. The inclusion of stronger reinforcement in the Al7075 alloy results in an enhancement in mechanical characteristics, including hardness, tensile strength, and compressive qualities, in comparison to the monolithic Al7075 aluminum alloy.

From the above literature review, it is found that many researchers have worked on the Aluminium based particulate reinforced composites. But the study of Al7475-ZrC composites has not been carried out so far. Also the impact of heat treatment on the Al7475-ZrC composites has not been studied till now. Hence the current study is aimed on the development of Al7475-ZrC composites. Also the present study focuses on the study of impact of heat treatment on the Al7475-ZrC. The developed composites are utilized in automotive components such as brake drums, pistons and connecting rods.

2. Materials and Methods

3.1. Matrix Material

The matrix material in the current investigation was Al7475 alloy, while ZrC was employed as the reinforcement material. Al7475 is a high-strength aluminum alloy that is predominantly recognized for its exceptional mechanical characteristics and high fatigue strength. The mechanical characteristics of the Al7475 alloy can be improved through thermal treatment. The typical heat treatment procedure involves solution heat treatment, which is followed by aging [21]. It is frequently employed in the aerospace industry for aircraft structures, such as fuselage frameworks, wings, and other critical components, as a result of its high strength-to-weight ratio. It is used in military applications where high strength and toughness are required. It is also used in sports equipment, like bicycle frames and high-end sporting goods, use this alloy. The composition of Al7475 is presented in the Table 1.

Table 1. Composition of Al7475 Alloy.

Element	Al	Zn	Mg	Cu	Cr	Fe	Si	Mn	Ti
Quantity (wt.%)	Balance	5.5	2.2	1.4	0.2	0.1	0.08	0.04	0.04

2.2. Reinforcement Material

Zirconium carbide is a compound with the chemical formula ZrC. It is a refractory ceramic material known for its high melting point and hardness. Zirconium carbide is commonly used in cutting tools, abrasives, and wear-resistant coatings due to its excellent mechanical properties. It has a cubic crystal structure. Zirconium carbide exhibits good thermal conductivity and electrical conductivity, making it suitable for applications in the aerospace and electronics industries [22]. It is also used as a catalyst support and in nuclear applications. Zirconium carbide is stable in air and has low toxicity. Overall, zirconium carbide is a versatile compound with a wide range of industrial applications.

2.3. Fabrication of Al7475-Zirconium Carbide Composites

The stir casting method was chosen as the appropriate approach for the purpose of producing composites. An electric arc furnace was used in order to conduct the stir casting process. In an electrical arc furnace, the graphite crucible was used to melt the Al7475 alloy at 700 ºC temperature. The mechanical stirrer made of stainless steel was inserted into the melt once the degassing process had been completed successfully. A vortex was created by stirring the molten alloy at a speed of 500 revolutions per minute. Zirconium carbide particles that had been heated to 400 degrees Celsius were introduced to the vortex that had been generated in a slow and steady manner while stirring continuously for ten minutes [23]. This was done to guarantee that the particles were completely dispersed across the metal matrix. After the stirring was complete, the stirrer was taken out of the

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mixture, and the molten composite was poured into the mold that had been preheated and coated. The mold was then allowed to cool. In order to achieve a variety of castings, the amount of $ZrO2$ particles that were added to the matrix alloy was adjusted in increments of 2%, ranging from 0 to 8 weight percent. The samples of the cast composite are displayed in Figure 1.

Figure 1. Developed Composite Samples.

2.4. Heat Treatment Process

A muffle furnace was used to perform a T6 heat treatment on the Al7475 matrix alloy as well as the cast Al7475-Zirconium carbide composites. Following the introduction of the composites into the furnace, the solutionizing process was conducted at 530°C temperature for a time period of two hours. After the solutionizing procedure, the specimens were quickly quenched in air and then subjected to artificial aging for six hours at 175°C temperature [24].

2.5. Testing of Al7475-Zirconium Carbide Composites

Following the ASTM standards, the generated composites were machined, and specimens were produced for the purpose of determining the Brinell Hardness Number, tensile strength, compression strength, and microstructure. Metallographic specimens were extracted from the cylindrical bars and obtained by the application of a technique that was specifically developed for the production of composites of this kind. For the purpose of etching the samples wherever it was necessary, a 0.5% HF setup was applied. An examination of the microstructures was performed using SEM. A standard known as ASTM E8 was followed in the production of tensile samples. The Instron testing device was employed in order to carry out the tension test. Compression samples were manufactured in accordance with ASTM standard, and the compression test was performed utilizing universal testing apparatus [25]. Accordance with ASTM standard, the Brinell Hardness apparatus was utilized in order to establish the composite specimens' individual levels of hardness. The hardness test was conducted following the HB 500 standard, using a ball indenter with a 10 millimeter diameter. To limit the risk of the indenter coming into contact with a rigid particle, which could result in an anomalous measurement, the experiments were conducted in three distinct orientations on the specimen. The Figure 3 presents the ASTM-sized standard specimen that was utilized for the tensile test, the hardness test, and the compression test.

In order to determine the Brinell Hardness of Al7475-ZrC composites, the equation (1) that is presented below is applied.

$$BHN=2P/\pi D\ (D-V\ (D^2-d^2\ )) \tag{1}$$

Where,
P = load applied (kgf)
D = diameter of indenter (mm)
d = diameter of indentation (mm)
The hardness sample is depicted in Figures 2 and 3, both before and after the testing process.

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Figure 2. Hardness Sample before testing.

Figure 3. Hardness Sample after testing.

Figures 4 and 5 shows the tensile strength sample before and after testing.

Figure 4. Tensile sample before testing.

Figure 5. Tensile sample after testing.

Figures 6 and 7 show the compression specimen before and after testing

Figure 6. Compression Sample before.

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Figure 7. Compression Sample after testing.

The sample before and after Impact test is indicated in the Figures 8 and 9.

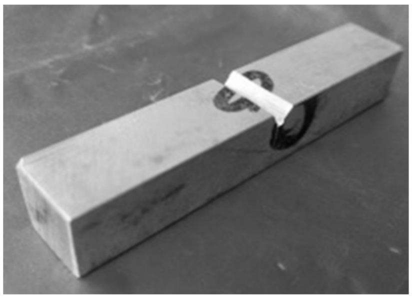

Figure 8. Impact Specimen before testing.

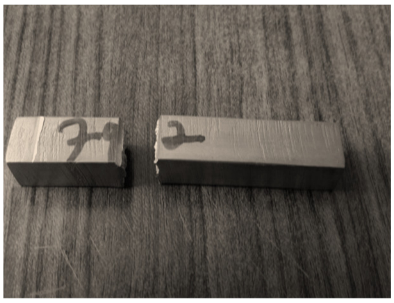

Figure 9. Impact Specimen after testing.

3. Results and Discussion

3.1. EDX Study of Al7475-Zirconium carbide Composites

The EDX Spectrums of Al7475-6%Zirconium carbide composite is indicated in the below Figure 10. It shows the presence of Aluminium, Zirconium and Carbon.

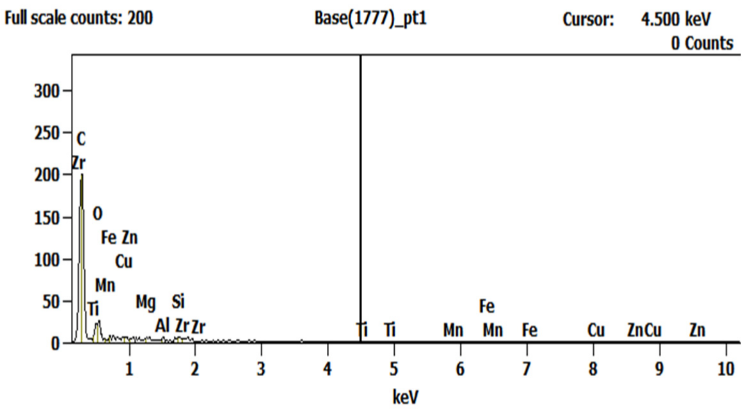

Figure 10. EDX pattern of Al7475-Zirconium dioxide composite.

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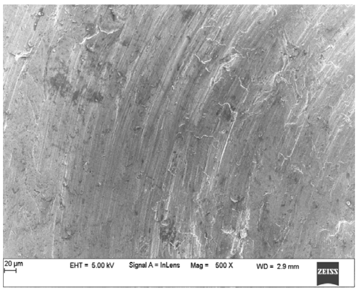
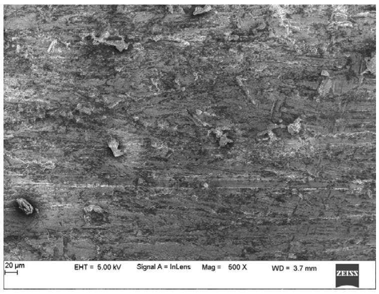
3.2. SEM Characterization of As-cast Al7475-ZrC Composites

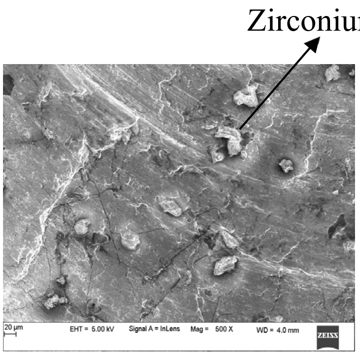
The SEM micrographs of as-cast Al7475 alloy, Al7475-2% ZrC, Al7475-4% ZrC, Al7475-6% ZrC and Al7475-8% ZrC composites in the below Figure 11a–d. An analysis of Figure 11b–d reveals that the Zirconium carbide particles are evenly distributed inside the Al7475 matrix. The uniform dispersion of ZrC particles in the Al7475 matrix is attributed to the preheating of the moulds and the continuous stirring of the molten material [26]. The scanning electron micrographs clearly demonstrate that the quantity of ZrC particles found in the Al7475 matrix rises proportionally with the quantity of ZrC particles introduced into the matrix. As the amount of ZrC particles that are added to the Al7475 matrix rises, the grain refinement that is present in the Al7475 matrix likewise increases. The size of the grains in Al7475-ZrC composites is reduced, which results in an enhancement in their strength.



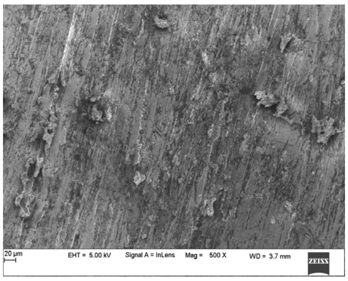
(**a**) Al7475



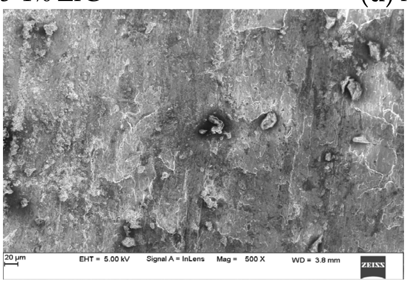
(**b**) Al7475-2% ZrC



(**c**) Al7475-4% ZrC



(**d**) Al7475-6% ZrC



(**e**) Al7475-8% ZrC

Figure 11. SEM micrographs of Al7475 alloy and Al7475-ZrC composites in as-cast condition for various percentage of ZrC.

3.3. SEM Characterization of Heat Treated Al7475-ZrC Composites

The SEM micrographs of heat treated Al7475 alloy, Al7475-2% ZrC, Al7475-4% ZrC, Al7475-6% ZrC and Al7475-8% ZrC composites are shown in the below Figure 12a–e. From the Figure 12b–d it is noted that, the zirconium carbide particulates are uniformly dispersed in the Al7475 matrix [27]. The scanning electron micrographs that are presented below demonstrate that the number of ZrC particles present in the Al7475 matrix increased when the amount of ZrC particles that are added increased. The SEM images 12 a) to 12 e) illustrate that the heat treatment effect leads to a higher

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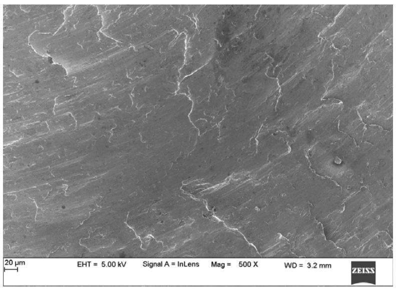
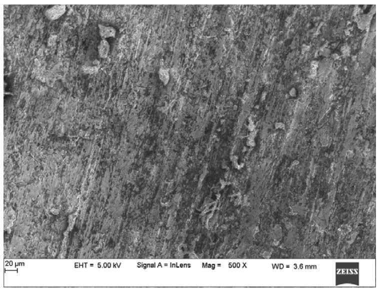
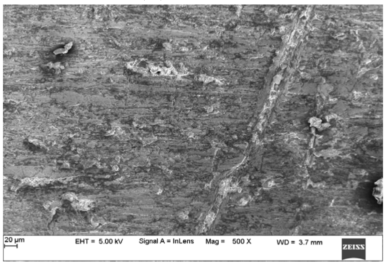
degree of grain refinement in composites. Due to the reduction in grain size, the composites exhibit an increased coefficient of strength.



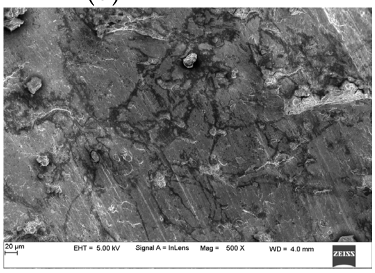
(**a**) Al7475



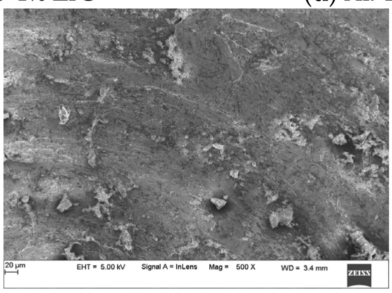
(**b**) Al7475-2% ZrC



(**c**) Al7475-4% ZrC



(**d**) Al7475-6% ZrC



(**e**) Al7475-8% ZrC

Figure 12. SEM images of Al6061 alloy and Al7475-ZrC composites in heat treated condition for various % of ZrC.

3.4. Tensile Strength Test Comparison between As-Cast and Heat Treated Al7475-ZrC Composites

The UTS values for Al7475-ZrC composites in as-cast and T6 heat treated condition are presented in Table 2.

Table 2. UTS Variation V/S % of Zirconium carbide of Al7475-ZrC composites in as-cast and heat treated condition.

Sl. No.	Composition	Ultimate Tensile Strength (N/mm2)	
		As-Cast	Heat Treated
01	Al7475+ 0% ZrC	80.25	99.13
02	Al7475+ 2% ZrC	83.34	103.54
03	Al7475+ 4% ZrC	91.57	109.71
04	Al7475+ 6% ZrC	104.42	121.95
05	Al7475+	98.81	116.46

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8% ZrC

An illustration of the variation in UTS v/s percentage of ZrC in as-cast and T6 heat treated Al7475- ZrC composites can be found in Figure 13. In the above figure, it can be seen that the UTS increases up to 6% of ZrC as the weight percentage of ZrC increases, and then it drops after reaching that concentration [28]. The reason for this is because the Al7475 alloy and ZrC particles have a low moisture absorption capacity. When it comes to Al7475-ZrC composites that have been cast and T6 heat treated, the optimal value of UTS is achieved when the percentage of ZrC is 6%. The UTS values of heat-treated Al7475-ZrC composites are greater than those of as-cast composites. This is because heat treatment causes a significant amount of grain refinement and the development of fine precipitates. The optimal values of UTS for as-cast Al7475-ZrC composites are 104.42 N/mm², whereas the values for T6 heat treated Al7475-ZrC composites are 121.95 N/mm² N/mm². When contrasted to as-cast composites, T6 heat treated composites exhibit a 16.78% increase in UTS because of the treatment process.

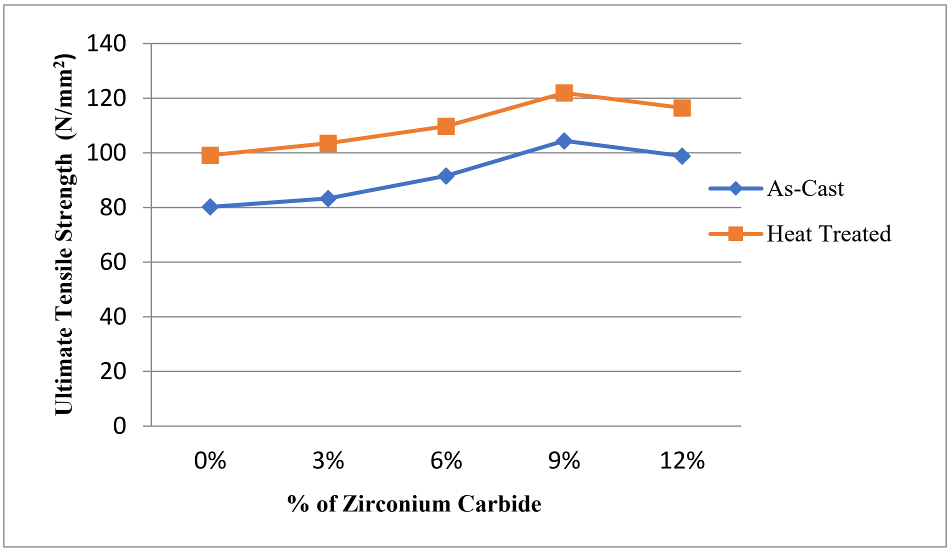
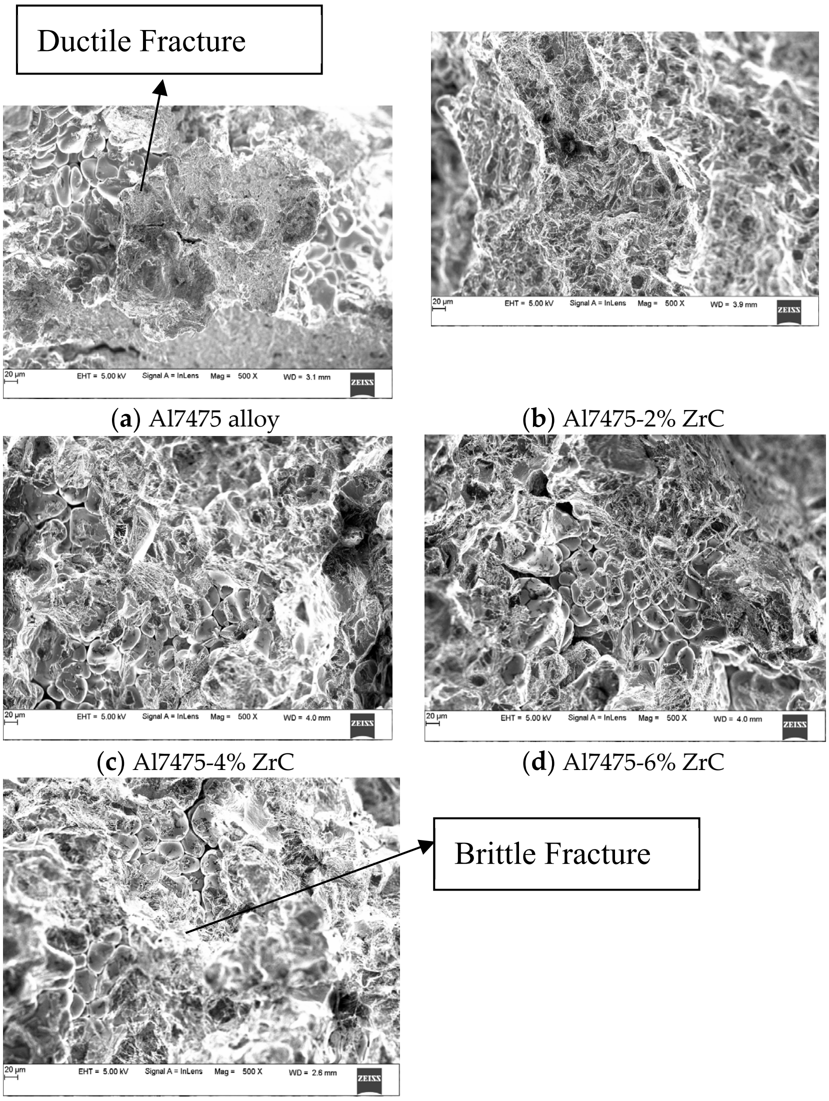


Figure 13. UTS Variation V/S % of Zirconium carbide of Al7475-ZrC composites In as-cast and heat treated condition.

3.4.1. Tensile Fracture Study of As-Cast Al7475-Zirconium Carbide Composites Using SEM

The Tensile fracture surfaces of as-cast Al7475 alloy, Al7475-2% ZrC, Al7475-4% ZrC, Al7475-6% ZrC and Al7475-8% ZrC composites are shown in the below Figure 14a–e. SEM is used to examine the tensile fracture surfaces of Al7475 alloy and Al7475-ZrC composites. The tensile fracture surface of Al7475 alloy is shown in Figure 14a indicates that the fracture of Al7475 matrix is ductile fracture [29]. It can be seen from the tensile fracture surfaces shown in Figure 14b–d that the number of ZrC particles that have cracked rises in proportion to the amount of ZrC particulates that are added to the Al7475 matrix. The strength of the composite increases as the broken zirconium carbide particles increases in the Al7475 matrix. The ductility of the composite reduces and brittleness increases as the ZrC particles increases in the Al7475 matrix. The fact that the Al7475-ZrC composites have become more brittle has resulted in an increase in their strength. The strength of the Al7475 matrix is another factor that contributes to the overall improvement in the composite's strength. In addition, the wettability between the Al7475 matrix and the zirconium carbide contributes to the enhancement of the composite's strength. This enhances the composite's overall performance. The tensile fracture surfaces shown in Figure 14b–e indicates that the ZrC particles are adhering to the Al7475 matrix. This also shows the fracture of the ZrC particles followed by Al7475 matrix fracture. The propagation of cracks in the Al7475 matrix is impeded by ZrC particles, which act as an obstruction. Because of this, the developed composite has more strength than the Al7475 matrix [30]. The scanning electron microscopy (SEM) photographs of the fracture surface of the Al7475-2% ZrC composite show a lower percentage of ZrC particles in the Al6061 matrix compared to the Al7475-6% ZrC composite. The composite's strength and resilience are imparted by the presence of zirconate chloride particles within the Al7475 matrix. There are more clusters of ZrC particles inside the given region of the fracture surface of the Al7475-6% ZrC composite, which results in enhancement in the composite's strength. In this particular instance, the particles are bearing a greater load than the matrix. As a result of the tensile test, it was discovered that the Al7475-6% ZrC composite possesses a higher level of strength than the Al7475 alloy. In the case of composites, the reinforcing particles are responsible for the brittleness.



(**a**) Al7475 alloy (**b**) Al7475-2% ZrC

(**c**) Al7475-4% ZrC (**d**) Al7475-6% ZrC

(**e**) Al7475-8% ZrC

Figure 14. Fractured Surfaces of Tensile Tested As-cast Al7475 alloy and Al7475-ZrC composites for various % of ZrC.

3.4.2. Tensile Fracture Study of Heat Treated Al7475-ZrC Composites Using SEM

The SEM images of Tensile fracture surfaces of heat treated Al7475 alloy, Al7475-2% Zirconium carbide, Al7475-4% Zirconium carbide, Al7475-6% Zirconium carbide and Al7475-8% Zirconium carbide composites are presented in the below Figure 15a–e. It is more likely that the grain refinement will be greater in composites as a result of the heat treatment impact. Because of this, the composites become more brittle. The strength of the heat treated Al7475-ZrC composite is more due to the grain refinement effect.

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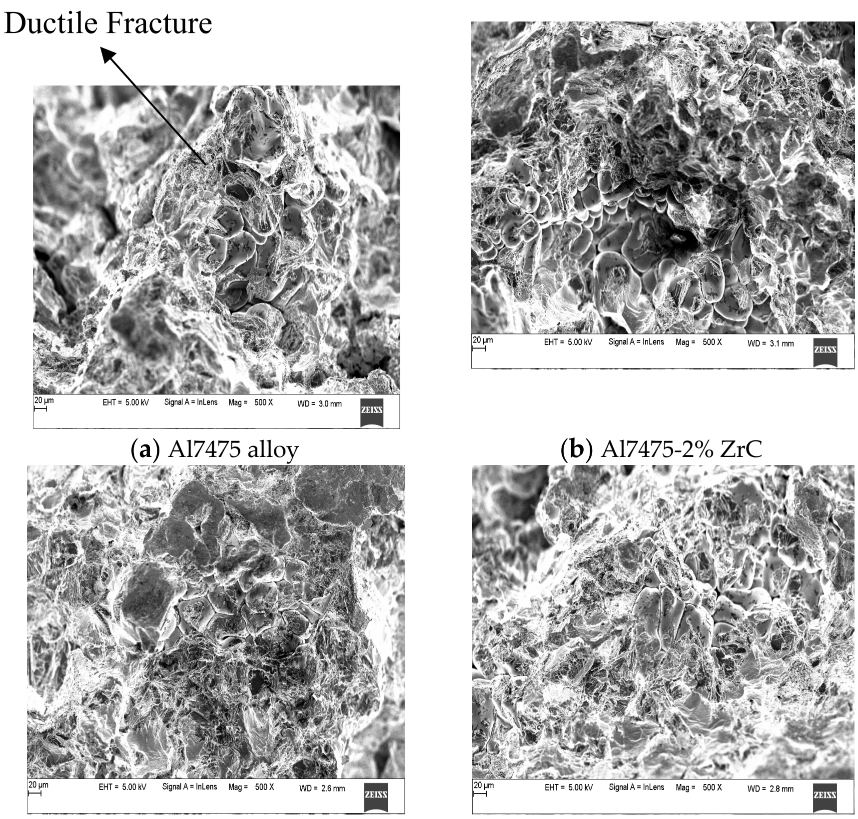
The tensile fracture surfaces indicated in Figure 15b–e shows that, the occurrence of fractured Zirconium carbide particles grows as the incorporation of zirconium carbide particulates increases in the Al7475 matrix [31]. The strength of the composite increases as the broken zirconium carbide particles increases in the Al7475 matrix. The ductility of the composite reduces and brittleness increases as the zirconium carbide particles increases in the Al7475 matrix. This leads to enhancement in strength of the composites. The tensile fracture surfaces shown in Figures 15.6 (b) to 5.6 (e) indicate that the zirconium carbide particles are adhering to the Al7475 matrix. This also shows the fracture of the zirconium carbide particles followed by Al7475 matrix fracture. The ZrC particles that are used as reinforcement in the Al7475 matrix serve as an impediment that prevents the fracture from spreading further. Furthermore, this yields in an improvement in the composites' strength in comparison to the Al7475 matrix. When contrasted to the Al7475-6% ZrC composite, the SEM pictures of the fracture surface of the Al7475-2% ZrC composite contain a lower percentage of ZrC particles in the Al7475 matrix. According to reference [32], the presence of ZrC particles in the Al7475 matrix gives the composite material the ability to withstand failure. The fracture surface of the Al7475-6% ZrC composite has a greater number of clusters of ZrC particles within the specified region, which yields in an improvement in the composite's strength. The particles are bearing a greater load than the matri in this particular instance. From the tensile test, it is found that Al7475-6% ZrC composite gives better strength than the alloy. In case of composite the reinforcement particles produce brittleness.



(**a**) Al7475 alloy (**b**) Al7475-2% ZrC

(**c**) Al7475-4% ZrC (**d**) Al7475-6% ZrC

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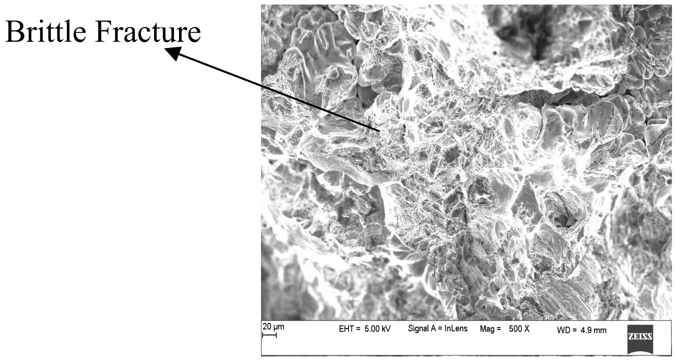

(**e**) Al7475-8% ZrC

Figure 15. Fractured Surfaces of Tensile Tested heat treated Al7475 alloy and Al7475-ZrC composites various % of ZrC.

3.5. Yield Strength Comparison of Al7475-ZrC Composites in As-Cast and Heat Treated Condition

The values of yield strength of Al7475-ZrC composites in as-cast and heat treated condition shown in the below Table 3.

Table 3. Yield Strength Variation V/S % of Zirconium carbide Al7475-ZrC composites of in as-cast and T6 heat treated condition.

Sl. No.	Composition	Yield Strength (N/mm^2)	
		As-Cast	Heat Treated
01	Al7475+ 0% ZrC	68.26	88.52
02	Al7475+ 2% ZrC	71.62	90.42
03	Al7475+ 4% ZrC	78.60	94.17
04	Al7475+ 6% ZrC	87.23	100.72
05	Al7475+ 8% ZrC	82.34	97.20

Figure 16 depicts the difference in yield strength proportional to the percentage of ZrC in Al7475-ZrC composites that have been as-cast and those that have been heat treated with T6 condition. Increasing the weight percentage of ZrC results in an improvement in yield strength up to 6% of ZrC, after that it decreases due to the agglomeration of reinforcement particles [33]. For both as-cast and heat treated Al7475-ZrC composites; the highest value of yield strength is achieved when 6% of ZrC is present. The yield strength values of heat-treated Al7475-ZrC composites are greater than those of as-cast composites. This is because grain refinement is extremely fine and fine precipitates are formed.

It has been determined that the optimal values of yield strength for as-cast Al7475-ZrC composites are 87.23 N/mm^2, whereas the values for T6 heat treated Al7475-ZrC composites are 100.72 N/mm^2. When contrasted to the as-cast composites, the yield strength of heat treated composites is 15.46% higher than that of its counterpart.

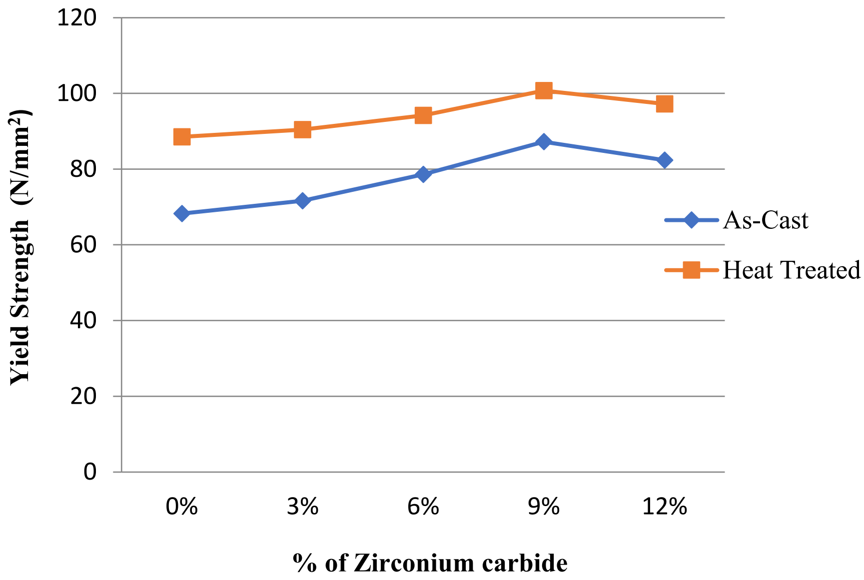

Figure 16. Yield Strength Variation V/S % of Zirconium carbide of Al7475-ZrC composites in as-cast and T6 heat treated condition.

3.6. Percentage Elongation of Al7475-ZrC Composites in As-Cast and Heat Treated Condition

The values of percentage elongation of as-cast and heat treated Al7475-ZrC composites are shown in the below Table 4.

Table 4. Percentage elongation Variation V/S % of Zirconium carbide of as-cast and heat treated Al7475-ZrC composites.

Sl. No.	Composition	Percentage Elongation (mm)	
		As-Cast	Heat Treated
01	Al7475+ 0% ZrC	27.14	25.73
02	Al7475+ 2% ZrC	26.47	24.54
03	Al7475+ 4% ZrC	25.31	22.86
04	Al7475+ 6% ZrC	23.56	20.41
05	Al7475+ 8% ZrC	24.28	21.55

Figure 17 illustrates the variance in percentage elongation vs percentage of ZrC in Al7475-ZrC composites that have been as-cast and those that have been heat treated in T6 condition. In the above figure, it can be seen that the percentage of elongation drops up to 6% of ZrC, and then it increases after that point. This is because the weight percentage of ZrC increases. The reason for this is because the Al7475 alloy and ZrC particles have a low moisture absorption capacity. It has been found that the highest possible value of percentage elongation may be achieved by using 6% ZrC in Al7475-ZrC composites that have been cast and T6 heat treated [34]. The % elongation values of heat treated

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Al7475-ZrC composites are less than those of as cast composites. This is because of the massive grain refinement and the generation of fine precipitates that happens during the heat treatment process. For as-cast Al7475-ZrC composites, the optimal values of % elongation are 23.56 millimeters, while for T6 heat treated Al7475-ZrC composites, the optimal values are 20.41 millimeters. A decrease of 13.37% in percentage elongation can be observed in composites that have been heat treated with T6 as opposed to composites that have been cast.

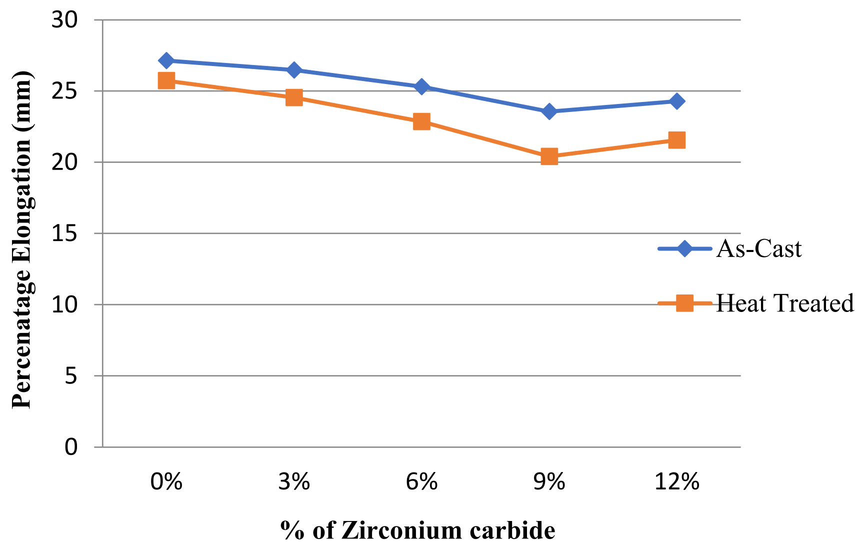

Figure 17. Percentage elongation Variation V/S % of ZrC of Al7475-ZrC composites in as-cast and heat treated condition.

3.7. Compression Strength of Al7475-ZrC composites in As-Cast and Heat Treated Condition

The values of compression strength of as-cast and heat treated Al7475-ZrC composites are given in the below Table 5.

Table 5. Compression Strength Variation V/S % of Zirconium carbide of as-cast and heat treated composites.

Sl. No.	Composition	Compression Strength (N/mm^2)	
		As-Cast	Heat Treated
01	Al7475+ 0% ZrC	532.35	678.25
02	Al7475+ 2% ZrC	555.42	693.23
03	Al7475+ 4% ZrC	598.67	735.44
04	Al7475+ 6% ZrC	665.43	789.68
05	Al7475+ 8% ZrC	636.38	765.13

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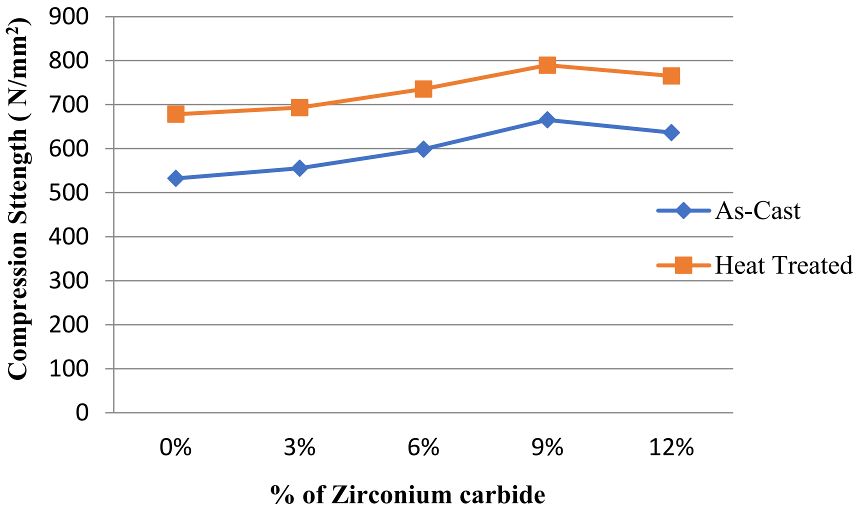

Figure 18. Compression Strength Variation V/S % of Zirconium carbide of as-cast and heat treated Al7475-ZrC composites.

Figure 6.4 illustrates the variance in compression strength V/S % of Zirconium carbide in Al7475-ZrC composites that have been as-cast and those that have been heat treated to T6 condition. Increasing the weight percentage of ZrC results in an increase in compression strength up to 6% of ZrC, after that it decreases. This is demonstrated by the figure that is previously mentioned. The reason for this is that the relationship between ZrC particles and Al7475 alloy has a low wettability [35]. The highest possible value of compression strength is achieved by adding 6% ZrC into Al7475-ZrC composites that have been cast and then subjected to T6 heat treatment. The values of compression strength for heat-treated Al7475-ZrC composites are higher than those of as-cast composites. This is because of the massive grain refinement and the generation of fine precipitates that occur during the heat treatment process. When it comes to compression strength, the optimal values for as-cast Al7475-ZrC composites are 665.43 N/mm^2, however the optimal values for T6 heat treated Al7475-ZrC composites are 789.68 N/mm^2. With regard to compression strength, T6 heat treated Al7475-ZrC composites exhibit an increase of 18.67% when compared to composites that have been cast in their original state.

3.8. Hardness Test of Al7475-Zirconium Carbide Composites in As-Cast and Heat Treated Condition

The values of BHN of as-cast and heat treated Al7475-ZrC composites are shown in the below Table.

Table 6. BHN Variation V/S % of Zirconium carbide of as-cast and heat treated Al7475-ZrC composites.

Sl. No.	Composition	Brinell Hardness Number	
		As-Cast	Heat Treated
01	Al7475+ 0% ZrC	81.53	114.21
02	Al7475+ 3% ZrC	84.48	116.35
03	Al7475+ 6% ZrC	92.35	120.29

04	Al7475+ 9% ZrC	103.74	126.86
05	Al7475+ 12% ZrC	98.41	123.24

The above Figure 19, illustrates the relationship between the percentage of ZrC and the BHN of as-cast and heat treated Al7475-ZrC composites. The above figure that demonstrates that the BHN rises up to 6% of ZrC as the weight percentage of ZrC increases, and then it begins to fall after reaching that point [36]. This is because reinforcement particles have found a way to cluster together. For Al7475-ZrC composites that have been cast and T6 heat treated, the BHN is at its highest when the percentage of ZrC is 6%. The BHN values of heat-treated Al7475-ZrC composites are greater than those of as-cast composites. This is because both the grain refinement and the generation of fine precipitates are significantly increased. When it comes to Al7475-ZrO2 composites, the optimal values of BHN are 103.74 BHN for as-cast composites and 126.86 BHN for T6 heat treated composites. The BHN of T6 heat treated composites grows by 22.28% compared to the BHN of as-cast composites.

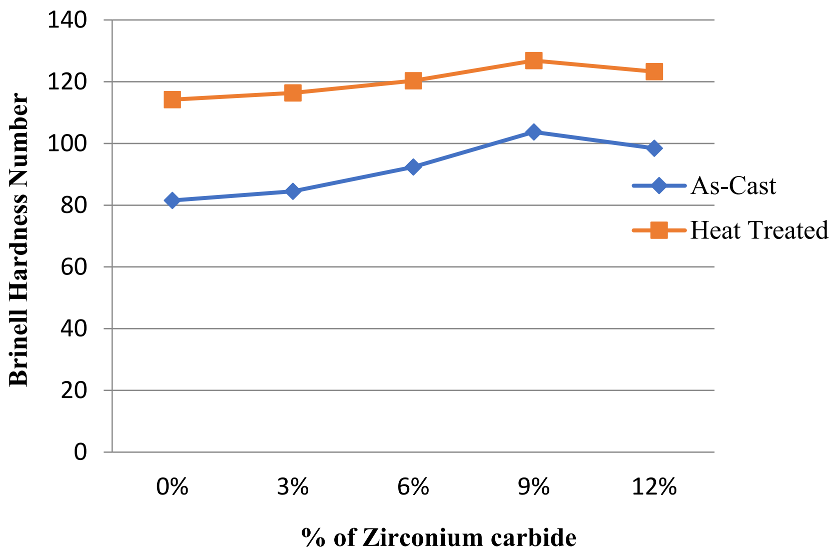

Figure 19. Brinell Hardness Number Variation V/S % of Zirconium carbide of as-cast and heat Al7475-ZrC composites.

3.9. Impact Strength Test of Al7475-Zirconium Carbide Composites in As-Cast and Heat Treated Condition

The values of Impact strength of as-cast and heat treated Al7475-ZrC composites are given in the below Table 7.

Table 7. Impact strength Variation V/S % of Zirconium carbide of as-cast and heat treated Al7475-ZrC composites.

Sl. No.	Composition	Impact Strength (J/mm²)	
		As-Cast	Heat Treated
01	Al7475+ 0% ZrC	12	15
02	Al7475+ 2% ZrC	13	16
03	Al7475+	14	17

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	4% ZrC		
04	Al7475+ 6% ZC	16	19
05	Al7475+ 8% ZrC	15	18

Figure 20 illustrates the extent to which the impact strength of as-cast and heat treated Al7475-ZrC composites varies in relation to the percentage of ZrC present in the material. According to the data presented in Figure 6.6, the impact strength of Al7475-ZrC composites increases up to 6% of ZrC, after which it begins to drop. This is the phenomenon that is depicted in the figure. The reason for this is that the Al7475 alloy and ZrC particles have a low moisture absorption capacity [37]. At a percentage of nine percent ZrC, the highest value of impact strength is achieved for Al7475- ZrC composites that have been cast and heat treated to the T6 level. The impact strength values of heat-treated Al7475-ZrC composites are higher than those of as-cast composites. This is because the heat treatment causes the grains to become extremely refined and causes the development of fine precipitates. The impact strength of Al7475 matrixes in their as-cast state is 0.11 J/mm^2, while the impact strength of matrixes that have been thermally treated with T6 is 0.14 J/mm^2. When contrasted to as-cast Al7475 matrixes, the impact strength of heat treated Al7475 matrixes is 9.09% higher than without heat treatment. In terms of impact strength, the optimal values for as-cast Al7475-ZrC composites are 16 J/mm^2, while the optimal values for T6 heat treated Al7475-ZrC composites are 19 J/mm^2. When contrasted to as-cast composites, the impact strength of T6 heat treated composites is 18.75% higher than without heat treatment.

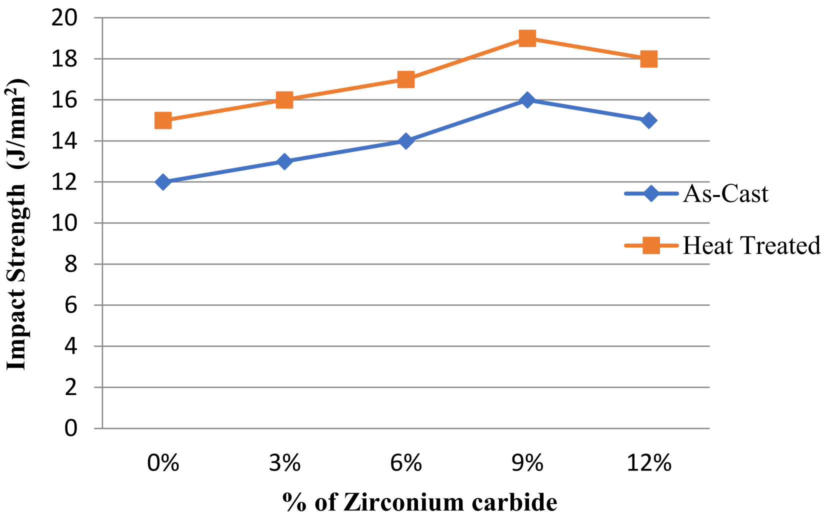

Figure 20. Impact strength Variation V/S % of Zirconium carbide of as-cast and heat treated Al7475-ZrC composites.

5. Conclusions

The conclusions drawn from the present study on Impact of Zirconium Carbide Particles on the Synthesis and Mechanical Characteristics of as-cast and heat treated Al7475-Zirconim Carbide Composites are as follows.

- The Al7475-ZrC composites were prepared by stir casting process. This was accomplished by adjusting the weight percentage of Zirconium carbide particles in increments of two weight percent, ranging from 0 to 8 wt.%.
- The EDX spectrum of the composite material Al7475-6% ZrC reveal the existence of aluminium, Zirconium and carbon.

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- The microstructure of the as-cast and heat treated Al7475-ZrC composites, revealed that the matrix of Al7475 alloy consisted of Zirconium carbide particles uniformly distributed throughout the matrix.
- The SEM images of heat-treated composite reveal that the grain size decreased as a result of the heat treatment effect, which in turn results in improvement in the strength of the Al7475-ZrC composites.
- The mechanical characteristics of the heat-treated Al7475-ZrC composites have been observed to be superior to those of the as-cast composites. These properties include Ultimate Tensile Strength, compressive strength, Brinell Hardness, and impact strength. When compared to as-cast composites, T6 heat treated Al7475-ZrC composites exhibit a 16.78% increase in Ultimate Tensile Strength.
- Composites that have been heat treated with T6 have a yield strength that is 15.46% higher than composites that have been cast.
- There is a 22.28% increase in the Hardness in composites that have been heat treated to T6 compared to composites that have been as-cast.
- The compression strength of heat treated composites is 18.67% higher than that of as-cast composites.
- When compared to as-cast composites, the impact strength of heat treated composites is 18.75% higher than that without heat treatment.

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Abbreviations

MMCs- Metal Matrix Composites; BHN-Brinell Hardness Number; UTS-Ultimate Tensile Strength; ZrC; Zirconium Carbide; SEM; Scanning Electron Microscope; EDX-Energy Dispersive X-ray Analysis.

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