Microstructure, Tensile Properties and Hardness Behavior of Al7075 Matrix Composites Reinforced With Graphene Nanoplatelets And Beryl Fabricated by Stir Casting Method

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Abstract: In this research, an effort is made to familiarize and best potentials of the reinforcing agent in aluminum 7075 matrices with naturally occurring Beryl (Be) and Graphene (Gr) to develop a new hybrid composite material. A stir casting technique was adopted to synthesize the hybrid nanocomposites. GNPS were added in volume fractions of 0.5wt%, 1wt%, 1.5wt%, and 2wt% and with a fixed volume fraction of 6 wt.% of Beryl. As cast hybrid composites were microstructurally characterized with scanning electron microscopy and X-ray diffraction. Microstructure study through scanning electron microscope demonstrated that the homogeneous distribution reinforcement Beryl and GNPs into the Al7075 matrix. Brinell hardness and tensile strength of synthesized materials were investigated. The hybrid Al7075-Beryl-GNPs composites showed better mechanical properties compared with base Al7075 matrix material. The as-cast Al7075-6wt.% Beryl-2wt.%GNPs showed 49.41% improvement in hardness and 77.09% enhancement in ultimate tensile strength over Al7075 alloy.

Keywords: Al7075, Beryl, Graphene, Stir casting, SEM.

I. INTRODUCTION

Aluminum alloys and its composites have outstanding mechanical properties and have attracted to carry out the research when compared to steel and other alloys. The most attractive attention characteristics of aluminum are its adaptability and flexibility [1]. The aluminum and its composites are made use in an aerospace and automobile industry owing to their better mechanical, thermal and tribological properties.The addition of ceramic reinforcements into the aluminum alloys metal matrix leads to development of suitable and comfortable engineering materials with higher strength to weight ratio [2-4]. Al MMC’s satisfy many engineering application and also provides convenient processing because of enough melting point of aluminum. The aluminum alloy consist of zinc, magnesium and copper as major alloying elements is belongs to 7xxx series and commonly known as Al7075 which has a high strength, corrosion resistance and hence it is typically used in aircraft fittings including gears, shafts and various other forms of commercial transportation, aerospace parts and also most widely used in structural applications[5-11]. Graphene is allotrope of carbon. Graphene attracted many researchers owing to its outstanding mechanical, thermal and electric properties. [12-15]. Graphene incorporation into aluminum matrix reports in enhancement of hardness, and tensile strength [16-20]. Graphene nanoplatelets (GNPs) are known to be multilayer Graphene. GNPs have many advantages over many reinforcements. Many researcher's studies reveal that Aluminum-GNPs reinforced composites synthesized by stir casting and powder metallurgy techniques showed better enhanced mechanical properties. The most important GNPs exhibit better bonding and wettability with aluminum. Rashad et al reported that claimed that, hardness and ultimate tensile strength of AZ31- 3wt.% of GNPs led to improvement when compared to AZ31 fabricated by stir casting process [21]. GNPs are having low density and hence increase the usage in lightweight applications where weight of metal matrix composites is to be reduced. The researchers claimed that addition of 2 wt.% GNPs increases the fracture toughness of Al_2O_3 by 53% (K. Wang et al.)[22]. The addition of 1.5 wt.% of GNPs in Si_3N_4 led to enhancement of fracture toughness by 136% (Walker et al) [23]. Beryl[Be] is a naturally available mineral. The incorporation of Beryl in Al MMCs enhances mechanical properties. Hosur Nanjireddy Reddappa et al. reported that the incorporation of Beryl particles into the Al6061 alloy significantly enhances the mechanical properties and reduces the wear of the Al6061-Beryl composites when compared to base Al6061 alloy. Al6061-10 Wt.% of Beryl showed, 15.38% of enhancement in tensile strength and also 8.9% of reducing in wear of Al6061- 10Wt.% of Beryl when compared to Al6061 alloy. However effect of Beryl and Graphene on Al7075 alloy has not been reported so far. In the present research, Al7075-Beryl-GNPs hybrid composites were fabricated by stir casting process. The microstructure characterization of the composites was analyzed using SEM and XRD analysis. The hardness, yield strength, and ultimate tensile strength were evaluated and compared with Al7075 alloy.

II. MATERIALS AND EXPERIMENTAL PROCEDURES

2.1 Matrix Material:

In this research, matrix materials selected is Al7075 alloy, the alloying elements of Al7075 include zinc, magnesium, and copper leads to corrosion resistance, high strength, and hardness. Al7075 alloy has exceptional properties and found

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in many aerospace components. The composition and detailed elements weight percentage of selected Al7075 alloy is shown in Table 1.

Table 1. Composition of Al 7075 Matrix alloy

Elements	Wt. %
Zinc	5.602
Magnesium	2.506
Copper	1.598
Chromium	0.253
Titanium	0.18
Iron	0.106
Silicon	0.001
Manganese	0.052

2.2 Reinforcing Materials:

Beryl (Be) is also acknowledged as Beryllium Aluminum Cyclosilicate. Its chemical formula is (Be3Al2 (SiO3)6). The major elements Beryl contains are Silicon oxide (Wt.% 62.12), Aluminum oxide (Wt.% 18.05), Beryllium oxide (Wt.% 8.24), Ferric Oxide (Fe2O3) and Calcium oxide (Wt.% 1.34). Beryl is a mineral, naturally occurs and very hard reinforcements. Beryl density is almost the same as aluminum of about 2600 to 2800 kg/m3.

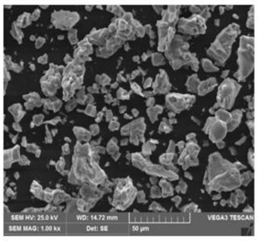

Figure 1. SEM micrograph of Beryl particles

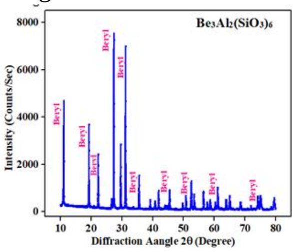

Figure 2. XRD patterns of Beryl

Figure. 1 represent the SEM image (scanning electron micrograph) of Beryl and Figure. 2 shows the XRD analysis of Beryl. The existence of Beryl and its hexagonal crystal structure was found in XRD analysis.

Graphene is pure carbon, a crystalline allotrope of carbon and has 98.5% of purity GNPs have a thickness of 5-10nm and the average diameter of 10-microns was procured from United Nanotech Innovations private limited, India. GNPs having a density of 2200 kg/m3 and anorthic (triclinic) crystal system.

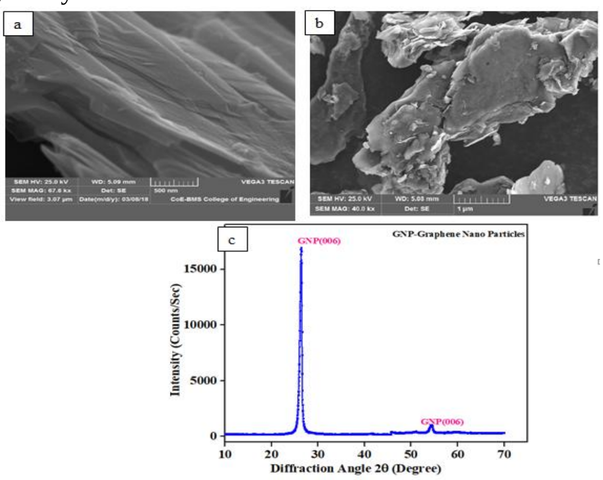

Figure 3. SEM image of as-received Graphene particles at (a) High magnification (b) Low magnification (c) XRD pattern of GNPs

Figure. 3 a & b shows the scanning electron micrograph of Graphene and Figure. 3 (c) shows the XRD analysis of Graphene. The anorthic crystal structure was found in XRD analysis.

2.3 Synthesis of Hybrid Al7075-Beryl-GNPs Composites

Stir casting, a most economical method for synthesis of hybrid Al7075-Beryl-GNPs Composites was adopted. Firstly 2kg of Al7075 ingots kept in a graphite crucible and was melted at 800 oC by using an electric furnace. A mechanical stirrer was used to create a vortex in an Al7075 melt. The stirrer speed maintained was 300 rpm. Then, preheated Beryl (6wt.%) and varying weight percentage of GNPs in steps of 0.5 Wt.% were added into the Al7075 melt. The stirring process continued for period of 5 minutes. A degassing tablet was used in order to avoid agglomeration and to remove the slag formed during the synthesis. The molten slurry of Al7075-Beryl and GNPs after stirring is discharged into the preheated cast-iron molds. The cast samples of Al7075 and Al7075-Beryl-GNPs composites were subjected to study the microstructure, hardness and tensile strength properties.

Table 3. List of composites prepared

Sample	Composites
A	Al7075
B	Al7075 – 6wt.% Be – 0.5 Wt.% GNPs
C	Al7075 – 6wt.% Be – 1 Wt.% GNPs
D	Al7075 – 6wt.% Be – 1.5 Wt.% GNPs
E	Al7075 – 6wt.% Be – 2.5 Wt.% GNPs

In order to study the tensile strength property of as-cast Al7075-Beryl-GNPs composites, samples were tested according to ASTM E8 standard. ASTM E10 standard was adopted to perform Hardness test.

2.4 Characterizations of Al7075-Beryl-GNPs

The fabricated Al7075 alloy and Al7075-Beryl-GNPs were first exposed to polishing. The surface analysis and tensile fracture surfaces of synthesized Al7075 and Al7075-Beryl-GNPs were carried out using a scanning electron microscope. The presence of Beryl and Graphene were analyzed using X-ray diffraction (XRD) method. The equipment used for XRD analysis was PANanlytical-X'Pert3 Powder.

III. RESULTS AND DISCUSSIONS

3.1 Microstructural Characterization

The microstructure of Al 7075 and hybrid Al7075/ Beryl / Graphene are shown in Figure 4. The microstructure study clearly reveals that the clear surfaces with minimal porosity. The SEM micrographs investigation reveals that microstructure consists of uniform distribution of fine Beryl, GNPs, and intermetallic compounds dispersed along the grain boundary in the matrix of Al 7075 and there is good bonding between Beryl, GNPs and Al7075 alloy. Uniform dispersal and better bonding of Beryl and GNPs within Al 7075 enhance the properties[21].

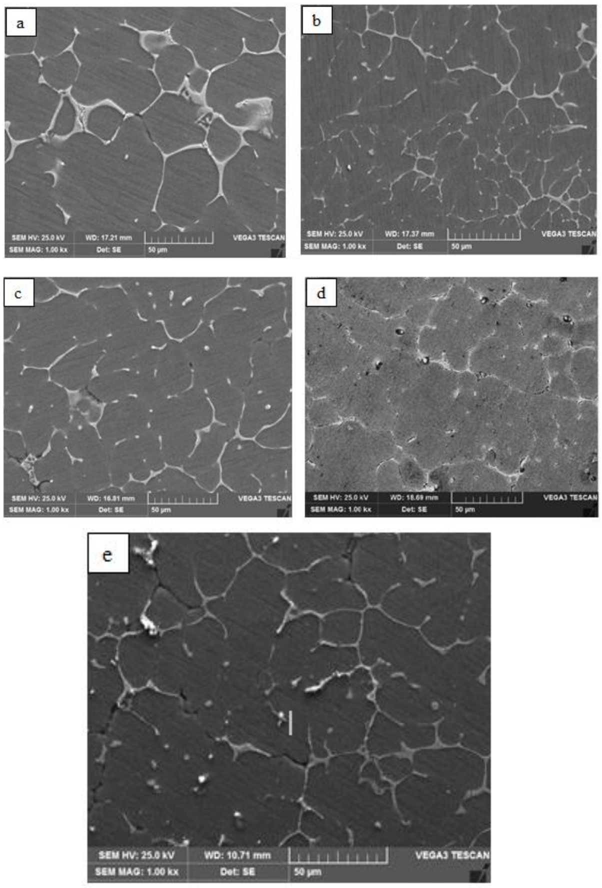

Figure 4. SEM micrographs of as-cast (a) Al7075 (b)Al7075-6wt%Be-0.5wt.%GNP (c) Al7075-6wt%Be-1wt.%GNP (d) Al7075-6wt%Be-1.5wt.%GNP (e) Al7075-6wt%Be-2wt.%GNP

3.2 X-ray diffraction analysis

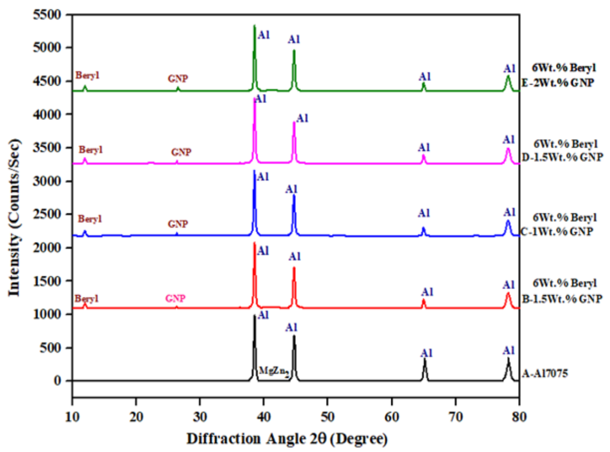

Figure 5. XRD patterns of as-cast Al7075 alloy and its composites

Figure 5 shows X-ray diffraction configurations of as-cast Al7075 alloy and hybrid reinforced with Beryl and GNPs. The XRD analysis study reveals that the peaks height increases as weight percentage of Graphene increases. X-ray intensities of peak 38°, 45°, 65° and 78° indicating the presence of aluminum phase[40]. X-ray intensity peak 26.2° indicates the presence of Graphene. X-ray intensity for Beryl particles indicates at 11.6° (2θ-angle). GNPs peaks have occurred at 26° [21]

3.3 Tensile Strength:

The results of the ultimate tensile test of Al7075 & Al7075-Beryl-GNPs (Hybrid composite) are tabulated in Table 5.

Table 5. Tensile strength results

Sample	Sample Designation	Ultimate Tensile Strength (MPa)
A	Al7075	130.776
B	Al7075 – 6wt.% Be – 0.5 Wt.% GNPs	198.358
C	Al7075 – 6wt.% Be – 1 Wt.% GNPs	208.724
D	Al7075 – 6wt.% Be – 1.5 Wt.% GNPs	219.831
E	Al7075 – 6wt.% Be – 2.5 Wt.% GNPs	231.587

The relationship between the UTS of the developed composites is shown in Figure 6.

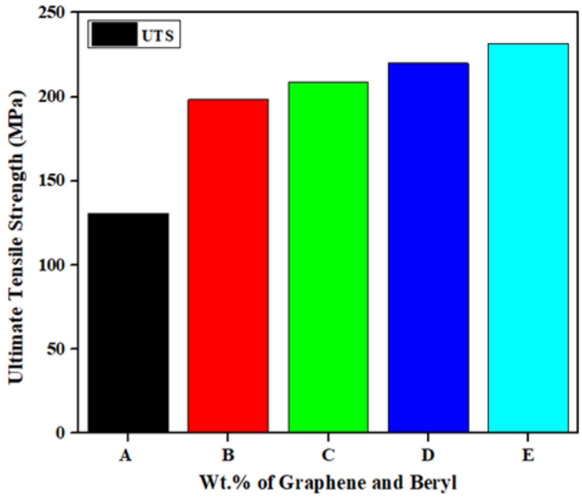

Figure 6. Ultimate Tensile strength of Al7075 and its composites

The tensile strength of the Al7075 alloy and Al7075-Beryl-GNPs were determined by using UTM. It is inferred from the test results that, the tensile strength of hybrid MMC increases with an increasing percentage of reinforcement and maximum tensile strength is achieved for 2 Wt.% of Graphene. This is because the Graphene and Beryl particles act as barriers to the dislocations related to thermal expansion divergence between Al7075 alloy, GNPs, and Beryl when the external load applied. The coefficient thermal expansion (CTE) for Al7075 alloy is 22.2 x 10-6 K-1, for Beryl 2.6 X 10-6 K-1 and for Graphene is 10-6 K-1. In addition, the elastic modulus of Al7075 alloy is 71 GPa, Beryl 287 GPa and Graphene nanoparticles between 0.7 and 1.2 TPa [39]. Thus, great differences between CTE and modulus of elasticity of matrix material and reinforcement led to the formation of dislocations at the interface. These dislocations at the interface will resist the external load and thereby leads to resisting the fracture. This resistance fracture leads to increase in tensile strength The tensile strength for Al7075-6 Wt.%Beryl-2 Wt.%GNPs showed enhancement of 77.09% as compared matrix material. Further incorporation of hard Beryl and Graphene particles into soft matrix leads to increased strength.

3.4 Yield Strength:

Table 6. Yield Strength results

Sample	Sample Designation	Yield Strength, MPa
A	Al7075	113.773
B	Al7075 – 6wt.% Be – 0.5 Wt.% GNPs	162.798
C	Al7075 – 6wt.% Be – 1 Wt.% GNPs	175.479
D	Al7075 – 6wt.% Be – 1.5 Wt.% GNPs	184.624
E	Al7075 – 6wt.% Be – 2.5 Wt.% GNPs	199.352

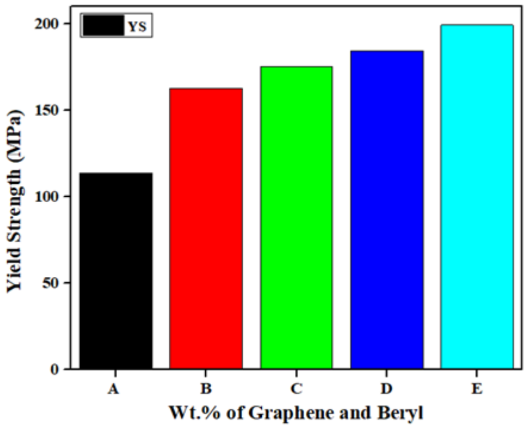

Figure 7. Yield Strength for different test samples

As the weight percentage of GNPS increases, yield strength of Al7075 and its composites increased. The maximum yield strength is achieved for 6wt.% of Beryl and 2 wt. % of Graphene (Sample E). This is because the Graphene and Beryl particles act as obstacles to the dislocations when the external load applied. Further incorporation of brittle and hard ceramic particles in a ductile matrix [24]. The hybrid composites having 6wt. % of Be and 2% of GNPs showed enhancement of 75.21% as related to Al7075 matrix material. The bonding, closer packing and smaller inter-particle spacing of reinforcement into the Al 7075 matrix alloy lead to an enhancement in strength.

3.5 Hardness

The results Brinell hardness number test on the Al7075 and its composites are shown in Table 7.

Table 7. Brinell hardness number results

Sample	Sample Designation	BHN
A	Al7075	84.8
B	Al7075 – 6wt.% Be – 0.5 Wt.% GNPs	110.3
C	Al7075 – 6wt.% Be – 1 Wt.% GNPs	115.6
D	Al7075 – 6wt.% Be – 1.5 Wt.% GNPs	121.2
E	Al7075 – 6wt.% Be – 2.5 Wt.% GNPs	126.7

The relationship between Brinell hardness number of the fabricated composites Al7075 and its composites are shown in Figure 8.

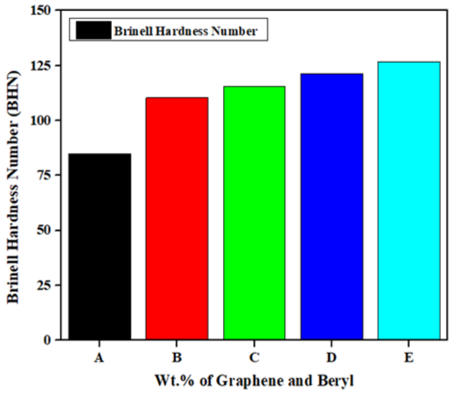

Figure 8. Brinell hardness of Al7075 and its composites

It is inferred from the test results that, the addition of GNPs and Beryl increasing weight percentage increases the hardness of Al7075 and its composites. The hybrid composites attain peak hardness on the addition of 6wt. % of Be particles and 2% of GNPs (sample E). The hybrid composites having 6wt. % of Beryl particles and 2% of Graphene showed enhancement of 49.41% as compared to Al7075 matrix material. This happens due to increases in the surface area of the matrix and the reduced grain size and Beryl particles are harder than Al7075. The presence of hard Beryl and GNP particles control to restricted deformation during indentation[21].

3.3 Fractography:

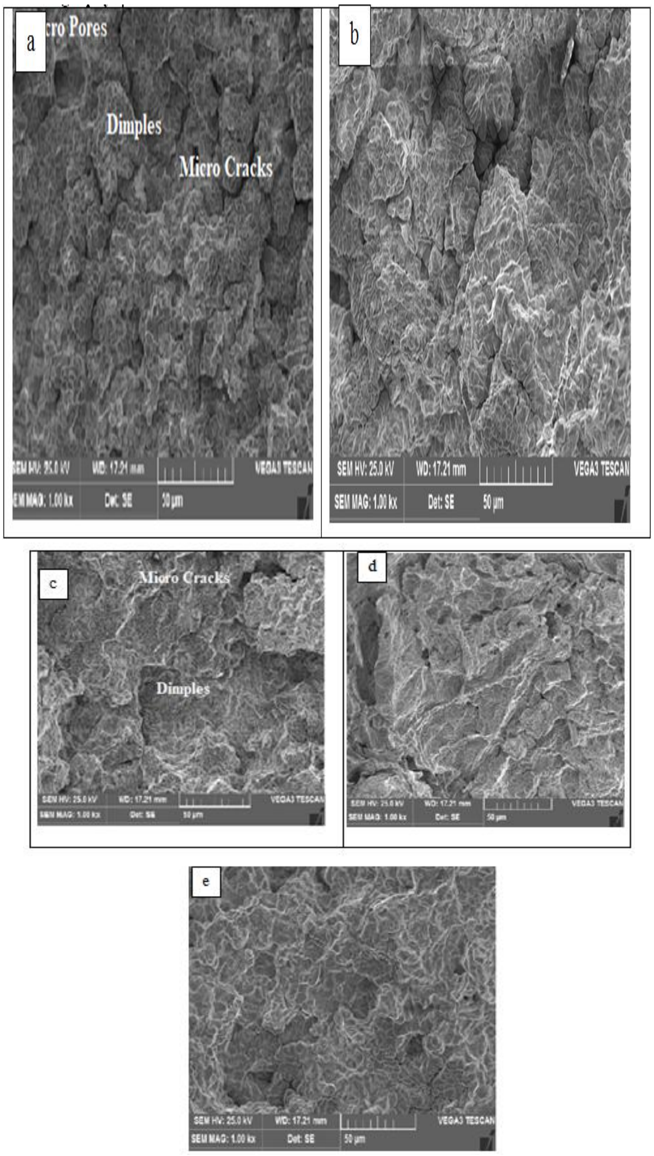

Figure 9: Tensile fracture surfaces of as-cast (a) Al7075 (b)Al7075-6wt%Be-0.5wt.%GNP (c) Al7075-6wt%Be-1wt.%GNP (d) Al7075-6wt%Be-1.5wt.%GNP (e) Al7075-6wt%Be-2wt.%GNP

Fractography was used to investigate the failure mechanisms of the materials. Figure 10 depicts the fractographs of fracture surfaces of as-cast tensile samples. Ductile fracture (Shallow Dimples) was noticed in Al 7075 base metal. SEM fractography study revealed that not fully brittle in appearance for the composites. It's a combination of ductile and brittle modes for the Beryl and Graphene reinforced composites. Also, it is observed that as the GNPs content increased, the dimples formation decreased and hence ductility decreases. The higher percentage of GNPS leads to brittle fracture and an increase in strength[21].

IV. CONCLUSIONS

1. Stir casting techniques were successfully adopted to synthesis the Al7075 and Al7075-Beryl-GNPs hybrid composites.
2. The mechanical (Tensile strength test and hardness) properties have been investigated for both the Al7075 and Al7075-Beryl-GNPS hybrid MMC.
3. The SEM analysis showed the homogeneous distributions of GNPS and Beryl particles into Al7075 alloy.
4. The ultimate tensile strength of Al7075-Beryl-GNPs composites shows a peak strength of 231.587 MPa at 6 wt.% of Be and 2 wt.% of GNPs particulate showing enhancement of 77.09% when compared to Al7075 matrix
5. The hardness of Al7075-Beryl-GNPs hybrid composites demonstrations an extreme hardness of 126.7 BHN at 6 wt.% of Be and 2 wt.% of GNPs particulate showing enhancement of 49.41% when compared to Al7075 alloy.
6. The XRD analysis has given the crystal structure and composition of Beryl and Graphene particulates.

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