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EFFECTS OF STIR CASTING PARAMETERS ON A356 ALLOY SYSTEM – A REVIEW

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ABSTRACT

Stir casting is a liquid state casting technology in which a mechanical stirrer is used to mix two different materials to produce castings with good mechanical properties. When it comes to the fabrication of aluminium-based alloy it is an economical and flexible process. Aluminum alloy A356 is frequently used in the automotive and aviation sectors as cast components with various section sizes due to their high strength-to-weight ratio and thixotropic structure. Its rigidity and specific tensile strength are better to those of other aluminium alloys and can further be improved by alloying with various elements. These characteristics result in light weighted cars and planes and improved fuel efficiency. The stir casting parameters play a significant role in producing alloys with good mechanical properties like ductility, strength, elongation, hardness, and toughness. In this paper an effort has been made to analyze the effects of stir casting parameters on the mechanical properties of A356-alloy based systems which have great demand in the modern industrial sectors. Tensile test, hardness test and microstructure analysis were conducted to evaluate the influence of casting parameter on respective mechanical properties. Optimum parameters for casting process were identified from the test results.

Keywords – A356, Casting Parameters, Stir casting, thixotropic

1. INTRODUCTION

One of the most widely used metals in the world, aluminium has numerous special qualities that make it useful in a variety of industrial fields. Its inherent qualities might be improved by the incorporation of additives or alloying materials. There are many different aluminium alloys on the market right now, but aluminium alloy 356 (A356) is one of the most significant alloys. A356 is a hypoeutectic aluminium alloy used in flow and structural parts of cars and aero planes. The elastic modulus of A356 alloys is around 70 GPa, or roughly around one-third of the elastic modulus of the commonly used types of steel and its alloys. As a result, for a given load, an A356 alloy component will flex more elastically than a component made of steel of the same size and shape. Despite the fact that some A356 alloys have somewhat greater tensile strengths than the commonly used types of steel Making Aluminum Metal Matrix Composites (AMMC) with ceramic reinforcements improves the mechanical and physical characteristics of the A356 alloy. Researchers have regularly tested boron carbide (B_4C) [1], carbon nanotube (CNT) [2], silicon carbide (SiC) [3], alumina (Al_2O_3) [4], and graphite (Gr) [4] as reinforcements in A356 alloy matrix in a number of research studies. Pramod et al [5] have reported the improvement of mechanical characteristics caused by the morphological transformation of eutectic silicon from a needle-like shape to a globular structure in the matrix following the inclusion of alloying elements and as a result of composites' T6 treatment. Table 1 displays the A356 alloy's chemical makeup. The production techniques and post-treatment of materials have typically been responsible for the variations inside the microstructure of the A356 alloy matrix. Stir casting is among the most popularly utilized production procedures for creating AMMCs. Controlling the process variables in different production processes prevents the clustering of reinforcement particles in the matrix. Table 2 lists the key physical characteristics of A356. Numerous studies have shown that the mechanical characteristics of the alloy system are greatly influenced by the casting parameters. Good tensile strength, hardness, toughness, and wear resistance are achieved with the proper use of optimal parameters. The paper's goal is to provide a thorough analysis of the potential effects of casting parameters on the mechanical characteristics of the cast A356 alloy system.

Table 1: Chemical constituents of A356 alloy

Element	Wt%
Si	6.89
Mg	0.26
Ti	0.010
Cu	0.008
Zn	0.002
Fe	0.080
Mn	0.004
Al	Balance

Table 2: Physical properties of A356alloy

Properties	Values
Melting point, ⁰C	750
Boiling point, ⁰C	2425
Density , Kg/cm^3	2.67
Crystal structure	FCC

2. STIR CASTING

The stir casting method is a liquid metallurgical process in which reinforcements are added to the molten matrix and the mixture is allowed to solidify. The most important thing in this situation is to ensure that the reinforcements and the molten aluminium or aluminium alloy properly moist; this is accomplished using the vortex technique, sometimes referred to as stir-casting, which is the simplest and most widely utilized technique. The vortex method includes. The vortex technique, devised to entail adding pre-treated ceramic particles into the vortex of molten aluminium alloy formed by the revolving impeller, reduces gravitational segregation in the crucible.

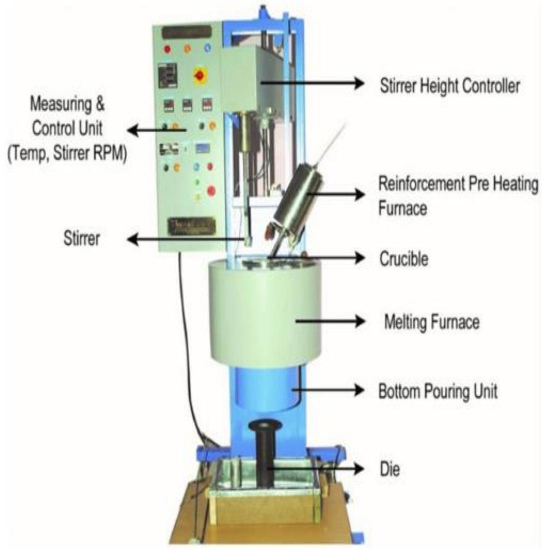

Fig 1 : Stir casting unit

Figure 1 shows schematic setups for stir casting. A furnace, a stirrer that is mechanically driven, and a reinforcement dispenser are all parts of the stir casting process. In a furnace, heat is used to melt the basic material. Because it does not give enough time for the molten mixture to stabilize at the bottom of the molten pot, the bottom pouring furnace is better suitable for the stir casting process. With the bottom pouring method, molten fluid may be fed instantly into moulds. To provide isotropic mechanical characteristics, the molten matrix material and reinforcing material must be properly mixed. A stirrer with a stirrer rod and blades is used to mix the ingredients. The stirrer's circular action creates swirls in the slurry, which results in appropriate mixing of the molten fluid. These mechanical stirrers can also be divided into groups according to their geometrical composition and the number of impeller blades. Favorable among all stirrers is one with an impeller made up of three flat blades [10]. It is brought on by the advancement of axial flow and decreased power consumption. With the stirrer's regulation speed motor linked to it for rotating motion, the speed of the stirrer may be adjusted. Along with the furnace, there is also a feeder for feeding the reinforcing material. The slurry may be applied to any mould and come in a variety of forms, including permanent and investment-grade. The first step of the process is to retain the matrix material in the furnace that has the lower feeding mechanism. The reinforcing agent needs to be heated before feeding in order to prevent impurities, moisture, and other issues. The preheating of reinforcing material necessitates the use of a separate furnace . Mechanically operated stirrer is initiated to create swirl after reaching the required temperature dependent on the matrix material. The reinforcing agent was let to descend through the feeder at a constant rate in the molten matrix material towards the direction of this swirl until the necessary amount of reinforcing material was mixed.

Inert gases like nitrogen and argon may also be used to extract hydrogen from molten metals like aluminium; this approach entails injecting bubbling inert gas into the liquid aluminium. The inert gas bubbles attract the hydrogen, which is subsequently pulled to them, transported up through the aluminum, and ultimately released on the surface [7]. In a new improvement, the melt is poured through the bottom part of the crucible as the moulds are being filled, stirring the composite.

3. STIR CASTING PARAMETERS

3.1 Stirring speed

The equal distribution of reinforcement in the matrix depends heavily on the production of a vortex, which is directly caused by the speed at which the mixture is stirred. Additionally, it affects the pattern of flow of molten metal and the wettability of matrix-reinforcement combinations. To ensure appropriate reinforcement dispersion in the matrix, a high-speed mechanical or ultrasonic stirrer must be used..

3.2 Stirring time

It is crucial to have the right amount of stirring time because insufficient stirring time leads to uneven particle dispersion and reinforcement aggregation in particular areas of the matrix [8]. When stirring is not done for an appropriate amount of time, it is seen that the reinforcement particles separate from the matrix. On the other side, an extremely long stirring period may result in the stirrer blade deforming.

3.3 Preheating temperature

Mould preheating removes the trapped gases from the slurry, which helps to eliminate the porosity. To get the desired qualities inside the composite, it is important to pre-heat the mould. Additionally, preheating the reinforcing material results in the reduction of moisture content and an improvement in wettability [8]. Therefore, it is necessary to warm the reinforcing material to a high temperature.

3.4 Pouring temperature

Maintaining a constant pouring rate and high pouring temperature will enhance casting quality and prevent gas entrapment. A greater pouring temperature would result in less porosity in the composite and better-distributed absorption of the reinforcing particles.

3.5 Melting Temperature

The impact of the melting temperature on composite materials is crucial. Any rise in casting temperature results in a drop in liquid viscosity along with an increase in stirring time, which also stimulates the matrix and reinforcement's adhesive qualities. Keeping the temperature at about 800 ºC will result in good wettability. When the temperature of the molten substance is lower, secondary particle accumulation takes place. Therefore, maintaining the molten at the ideal temperature is necessary.

3.6 Stirrer blade angle and design

To avoid the interaction between alloys and stainless steel at higher temperatures, the typically used blade for stirring purpose is made of stainless steel and has been coated with zirconia. The number of blades and blade angle determine the direction of liquid metal flow. The stirrer is submerged in molten metal to a depth of two thirds. To achieve a consistent material grain distribution, modifications in the stirrer shape and feeding mechanism are required. To prevent flaws in the finished cast product, molten material may be poured and stirred in an inert environment..

3.7 Particle incorporation rate

It is the rate at which the particles are supplied to the molten base material by using a reinforcement or feeder unit. Faster incorporation rate can cause clustering of particles or uneven distribution of reinforcements in the matrix.

3.8 Degassing

As aluminium melts, it begins to react with the oxygen in the air, which leads to the formation of an oxide layer on top. This oxide layer will prevent additional oxidation, but it will be challenging to break. As a result, mixing metal reinforcement with such a layer will be extremely difficult. Therefore, a degassing agent should be applied to prevent this.

4. EFFECTS OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES

L.Saravanan and T. Senthilvelan produced nano-Al_2O_3 aluminium composite utilizing a three-step mixing and stirring casting technique. Its dispersion was examined and contrasted with the properties of a nanocomposite made using a traditional technique and the basic matrix alloy. A 300 rpm stirring speed was used for the fabrication. The findings from scanning electron microscopy revealed homogenous dispersion.

Niranjan et al. [10] examined the impact of reaction time, temperature, and mass fraction on the titanium diboride (TiB_2) reinforcement in the in-situ-fabricated A356 aluminium alloy. Temperature was between 800 and 1000 ºC, the mass fraction of reinforcement ranged from 2 to 6%, and the reaction duration was between 20 and 40 minutes. Designing experiments with the use of response surface approach, three components, and a central composite design with five levels were taken into consideration. Tensile strength and hardness of composites were evaluated through experiments. The hardness and tensile strength of composites were predicted mathematically using the findings. The findings highlighted that on increasing the mass proportion of reinforcement enhanced the hardness and tensile strength of composites. According to the results of the significance tests, it was found that the reaction time and mass percentage of reinforcements had a substantial effect on the hardness number and tensile strength of composites. After the careful analysis of variations in results, it was determined that the proposed models were sufficient. Maximum hardness and tensile strength were achieved by optimizing the process parameters.

L. Shan et al.[11] in their work studied the impact of adding multi-walled carbon nanotubes (MWC-NTs) at different weight percentages on the stress-strain behavior and creep phenomena of an aluminium alloy called A356 was examined. Investigated was the impact of nickel plating on 0.2 wt% MWCNTs. The stir-casting technique was used to create the samples. The outcomes showed that the introduction of MWCNT nano-particulates caused the grain size to become finer. FESEM examination showed that the MWCNTs were evenly distributed throughout the A356 matrix, however certain agglomerations with sizes less than 100 nm were seen in a particular region. The hardness of alloys containing 0.2 weight percent, 0.2 weight percent nickel-coated, 0.5 weight percent, and 1 weight percent MWCNTs was found to be improved by 9%, 24%, 32%, and 15%, respectively, when they were compared to the unreinforced A356 matrix. The greatest value obtained with 0.5% MWCNTs was 87 BHN, representing a 32% increase in comparison to the base alloy. The inclusion of MWCNTs increases the hardness. In addition, compared to the uncoated nanoparticles, the yield stress rose by 37%, the ultimate tensile stress by 20%, the highest hardness by 14%, and the maximum extension by 16%. Additionally, it was discovered that the 0.5 wt% MWCNT-A356 matrix showed a creep lifetime enhancement of more than two degrees of magnitude.

A. Mazahery et al. [12] investigated the microstructure of stir-cast nanocomposites made of the aluminium alloy A356 and augmented with nanoSiC particles. The findings demonstrated that the nanosized SiC particles have been effectively incorporated into the aluminium matrix and that the porosity of the composites increases with increasing SiC volume fraction, which is explained by the large surface area of the nanoSiC particles. Additionally, a very homogeneous dispersion of SiC nano particles was seen inside the Al matrix. [27].

Ankit Rawat et al. [13] Created MMC ingots, mechanical stir casting procedures were utilized. SiC particles were added to the molten aluminium alloy at different weight percentages of 2, 4, and 6. By using an optical microscope, tensile strength, Brinell hardness, and impact strength tests, the heat-treated aluminium-based MMCs were characterized. According to the experimental findings of the A356/SiC composite, the inclusion of SiC ceramic particles significantly improves the base alloy's hardness, tensile strength, and impact resistance. The increased bonding between the ceramic reinforcement and reduced internal stresses in the metal matrix aluminium alloy caused the tensile strength and impact strength to increase by 15.58% and 10.25%, respectively, while the hardness decreased by 6.5% as a result of the heat treatment.

Hossein Abdizadeh et al.[14] investigated effects of ZrO_2 concentration and casting temperature on the mechanical characteristics and fracture behavior of A356 Al/ZrO2 composites have been studied. A356 aluminium alloy matrix composites reinforced with 5, 10, and 15 vol% ZrO_2 were created using the stir casting technique at different casting temperatures, namely 750, 850, and 950 °C. Based on the findings, the density and mechanical characteristics of the composites were assessed in order to identify the ideal level of reinforcement and casting temperature. In order to determine the mechanical characteristics of the composites, tests for hardness and tensile strength were performed. To determine the primary fracture mechanism(s) of the composites, the fracture surfaces of the specimens were also investigated. The findings show that the matrix alloy's inter-dendritic cracking caused all samples to shatter. ZrO_2 particles added to the Al matrix alloy increased its ultimate tensile strength and hardness to maximum values of 232 MPa and 70 BHN, respectively. Consequently, the specimen generated at 750 °C and containing 15% ZrO_2 had the best mechanical characteristics.

Ali Z et al. [15] focused on the investigation on A356 alloy composites with 3 wt% B_4C (40 & 90 m) particles. By using electron microscopy, the micrographs of the composite were examined, and micrographs were obtained to see where the B4C particles were located in the matrix. Additionally, the mechanical conduct of as-cast A356 combination composites (40 & 90 m) containing 3 wt% of B_4C composites was examined. ASTM scales were used to test mechanical qualities such as hardness, UTS, and yield quality. Microstructural analysis revealed the A356 composite's composite particles were uniformly scattered. The examination revealed that the existence of B_4C particles in the composite significantly increased the hardness, Ultimate Tensile Strength, and Yield Strength of the material.

Hamedan et al [16] examined the effects of the latest stir casting method's most effective factors on the microstructure as well as the mechanical properties of A356-1 wt% SiC nanocomposites, including master powder type stirring rate and temperature. A SEM (scanning electron microscope) and the X-ray diffraction method were used to interpret the microstructure and assess the mechanical characteristics using room temperature tensile and compression tests. The analysis demonstrated that the optimal mechanical characteristics and nanoparticle dispersion in the matrix were attained at a particular stirring rate and temperature. At stirring temperatures and rates that were greater or lower than the specific parameters, the characteristics and distribution both suffered. At high stirring temperatures and rates, these degradations were strong. Additionally, using a master powder with a reduced volume proportion of nanoparticles improved the resulting nanocomposite's mechanical characteristics and nanoparticle dispersion. The specific figures for stirring temperature and stirring rate among the many tested values for the parameters were 750 °C and 700 rpm, respectively.

Ansari Yar et al. [17] used stir casting to fortify the A356.1 Al alloy with MgO particles with a size of 50 nm. According to their experimental study, the reinforced specimens were harder than the foundation specimen. Additionally, when the melt temperature rises from 800 ºC to 950 ºC, the hardness rises. Additionally, in contrast to the control sample, the reinforced materials had better tensile and compressive characteristics.

S.A. Sajjadi et al. [19] investigated the mechanical characteristics of stir cast A356-Al_2O_3 micro and nanocomposites. A356 alloy was supplemented with 1, 2, 3, and 4 wt% of nanoparticles and 1, 3, 5, and 7.5 wt% of microparticles. To create the composite samples, Al_2O_3 particles with diameters of 20 m and 50 nm were utilized, and the speed for stirring was set to 300 rpm. They claimed that when the reinforcing % rises, porosity also climbs. The percentage of porosity was found to be the same for 1% micro and Nano reinforcement addition. They discovered that hardness rose as the mass proportion of micro and nanoparticles rose. Up to 5% weight percent of micro sized Al_2O_3 reinforcing particles were said to boost the yield and ultimate tensile strength of the micro composite before they started to decline. Strength for nano-composite enhanced up to 2wt.% reinforcement particles addition after that it decreased.

S. Amirkhanlou et al. [20] investigated stir-cast A356-5% SiCp composites were created [15]. SiC powder or particulate (Al-SiCp)cp composite powder, both of which were made by low energy ball milling equal volumes of commercially pure aluminium powder with a standard particle size of 80 m and SiC powder with an average grain size of 8 m for 52 hours, were added as reinforcements. 10% of the volume of the composite powder (Al-SiCp)cp was introduced into the melt of the A356 alloy as the reinforcement. The graphite stirrer was used to stir the mixture at a constant 500 revolutions per minute. The carrier gas for the introduction of reinforcements was argon gas. The dispersion of SiC particles in samples of A356-SiCp composites was less uniform than in samples of A356-(Al-SiCp)cp composites, according to their main results. Porosity content was lower in A356-(Al-SiCp)cp composites than in A356-SiCp composites. A356-(Al-SiCp)cp composites had greater hardness and impact energy than A356-SiCp composites.

Arda C¸ et al. [21] investigated the influence of solidification rate on cluster development in an Al-Si-Mg (A356) alloy composite strengthened with SiC granules. Using the closest neighbor and local density statistics, the observed degree of clustering in composites was assessed in terms of changes in dendritic arm spacing and solid percentages at the dendrite coherencies. The findings show that the secondary dendrite arms are in charge of regulating the SiC particle dispersion. Clustering is most prominent at distance scales between 150m and 500m, which were substantially greater than the nearest neighbor distances, depending on dendritic arm spacing and particle composition.

M. Karbalaei Akbari, et al [23] A356 matrix composites treated with TiB_2 nano (average size 20 nm) and micro (average size 5 m) particles were studied for their tensile behavior. 0.5, 1.5, 3, and 5 volume % of nano- and micro-sized TiB2 powders were employed to create the composites. At casting temperatures of 750, 800, and 900°C and in an inert environment of argon gas, the stirring operation was conducted at a continuous speed of 450 rpm between a time interval of 8 minutes. After that, the cast specimens were heated to T6 state. The porosity content of composites rose, according to the results, as the quantity of reinforcement component in the matrix material and reinforcement particle size decreased. With the increase of casting temperature, the porosity content rose. When 1.5 vol.% TiB_2 nanoparticles were supplied to the A356 alloy, notable enhancements in tensile strength and toughness were produced; additional increases in nanoparticle content resulted in a decrease in strength values. Nano-composites outperformed their micro-particle reinforced counterparts in terms of toughness and ductility.

Yunhui Du et al. [24] investigated the radial disposal of SiC particles in A356 liquid at a gradient angle of 25 degrees and a stirrer speed of 10 millimeters per second. The findings demonstrate the existence of a nonlinear relationship between the stirrer's speed of rotation and the radial relative fluctuation in the SiCp concentration of the A356 liquid between the center and the crucible's rim. The radial relative variation of the SiCp concentration in the A356 liquid grows larger and the radial distribution of the SiC particles becomes more irregular the faster the stirrer rotates. Furthermore, the vertical arrangement of SiC particles in A356 liquid is comparatively uniform when the stirrer's rotational speed is 200 r/min or less.

Phuriphut Saenpong et al. [28] has focused on analyzing the mechanical performance of stir-cast A356 matrix composites reinforced with varied weight percentages of SiCp. According to the study, keeping a favorable stirring speed of 300 rpm for 15 minutes improved the mechanical characteristics of composites made of A356-SiC. The microstructural study shows that SiC is evenly distributed throughout the matrix. By raising the weight percentage of SiC reinforcement to 15%, a greater hardness value of 74 HB was achieved, however at 20% SiC, fine cracks between the interface were seen and the hardness value dropped to 71 HB.

Sajjadi et al. [29] examined the impact of stirring speed and reinforcing particle weight percentage on the dispersion of particles in composite material. Al_2O_3 was chosen as the reinforcing particle and added to the matrix material at various weight percentages. Stirring was done at various speeds of 200 rpm, 300 rpm, and 450 rpm. SEM (scanning electron microscopy), OM (optical microscope) with image analyzer, EDS (energy dispersive spectroscopy), and X-ray diffraction were used to identify the consequences of these inputs. (XRD). According to reports, 300 rpm was deemed the most suitable stirring speed out of all others.

Hossein Abdizadeh et al. [31] used stir casting to create A356 aluminium alloy with MgO nanoparticles (1.5, 2.5, and 5% vol.%). At varied processing temperatures of 800, 850, and 950 C for stir casting, properties of micro MgO reinforced Al composites were examined. Results showed that raising the MgO vol.% from 1.5 to 2.5 with different processing temperatures causes density to rise. MgO concentration rises from 1.5 to 2.5 vol% at all temperatures, increasing hardness as a result of MgO's hardness. In contrast, samples with 5 vol.% MgO are less hard than samples with 2.5 vol.% MgO, which may be because micro-pores are forming at the MgO-Al matrix contact, which lowers the hardness of the sample.

S. P. Dwivedi et al. [33] concentrated on the production of modified electromagnetic stir cast aluminium matrix composites enhanced with varying proportions of SiC particles and fly ash. During the stirring phase, the overall distribution of SiC particles and Fly-ash in the matrix was improved by adding externally supplied argon gas to the molten metal. Five samples of a hybrid composite containing varying amounts of fly ash and silicon carbide (25 lm) were obtained by the electromagnetic stir casting method. All five samples' microstructure and mechanical characteristics, including fatigue strength, hardness, impact toughness and tensile strength were examined. The matrix's reinforcements (SiC particles and fly ash) are dispersed evenly according to the microstructure. (A356). The findings demonstrate that among the chosen samples, the sample of A356/15%SiC/5% Fly-ash exhibits the greatest performance. To determine the impact of adding Fly-ash, specific strength, porosity, thermal expansion, and density were also determined.

5. APPLICATION

A356 based alloy systems are commonly used in aviation engines, airframes, and landing gear. Due to its enhanced creep and corrosion resistance, A356 alloys are typically employed in aircraft applications. For space applications and missile, it's crucial to have high specific strength, stiffness, and simplicity of manufacture. The A356 alloy is presently being used to its fullest potential in the automobile industry, which is its newest benefactor. Common applications include automobile gearbox cases, fittings and control components for airplanes, and water-cooled cylinder blocks. Structural parts of aircraft including the engine control units, nuclear energy systems, and other applications requiring high-strength permanent moulds or castings are examples of other uses where excellent castability along with good weldability, good corrosion resistance and pressure tightness are required.

6. CONCLUSION

The paper critically examined a number of journals that utilized the process of stir casting for the production of A356 based alloy system. The review highlights the important stir casting parameters and also identifies the prominent effect of these casting parameters on the properties of A356 alloy systems. It covers the consequences of tuning the process variables and their best suited values for getting desired properties in developed AMCs by stir casting process. A good balance between strength, ductility, hardness and other mechanical properties with minimal defects can be achieved by taking the optimum parameter values during the fabrication process. The study of consequences of stirring speed, impeller blade angle, stirring duration, impeller blade size and feed rate of particle was done and following conclusion were drained out:

- Stirring temperature should be between 700–770 ºC.
- Stirring speed is assumed to be of the range 600 – 800 rpm.
- Stirring time is considered between 10–15 minutes.
- Reinforcement preheating time should be 2 – 4 hours based on the type of reinforcement material used.
- Preheating temperature should be of the range 200 – 350º C.
- The ideal blade angle is selected between 45-60º.

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