Methods to Improve the Performance of Aluminum Alloy

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Abstract Aluminum alloy has a lot of benefits including high strength, great ductility and low density. It is widely used in vehicle engineering, aviation, aerospace and so on. However, there is a higher requirement for aluminum alloy in these fields. For instance, higher strength, higher hardness, higher elongation and other performances are needed. Changing the content of certain elements, combination with graphene, plasma spraying and heat treatment might be four effective methods to improve the performance of the aluminum alloy. The experiments verify the effectiveness of each method. Still, there should be more studies on these methods to reveal the principle of each method.

1. Introduction
Aluminum is the mental element with the highest content in the earth’s crust. However, it is not until the 19th century did people start to use aluminum. For its strong reduction, alumina cannot be reduced by hydrogen or carbon monoxide, so it is hard to produce aluminum from aluminum ore. Later on, aluminum was found to have much better properties so it was used widely. Compared with steel, aluminum alloy has a similar strength to that steel and has much lower density. And because of the dense alumina film on its surface, it is hard to be oxidized in normal conditions. Nevertheless, some properties of aluminum still cannot meet the requirement of people. A higher request such as stronger electric conductivity, better corrosion resistance or greater tensile strength needs to be put forward. This article summarizes some methods to improve the performance of aluminum and gives some suggestions for future research.

2. Methods
2.1. Changing the element content
Most aluminum alloys contain more than 85 % aluminum, which means that the total amount of other elements does not exceed 15 %. However, other elements have a great influence on the properties of aluminum alloys. The mechanical properties of aluminum such as hardness, tensile strength and elongation alloys vary greatly with the content of trace elements.

Adding a certain amount of Y to the aluminum alloy has an obvious refinement effect on the microstructure of the alloy. The microstructure of the alloy without Y addition is mainly coarse columnar crystals with uneven distribution. After adding Y, the microstructure was refined and the distribution became uniform. Macroscopically, when the addition of Y is 0.1 % ~ 0.3 %, the mechanical properties of aluminum alloy gradually improve with the increase of Y addition. When the addition amount of Y was 0.3 %, the tensile strength and elongation of the alloy reached 154 MPa and 22.5 %, respectively [1].
In recent years, researchers have found that adding Ce to aluminum alloy can improve the mechanical properties of aluminum alloy. Adding a small amount of Ce to the aluminum alloy, the mechanical properties of the alloy are improved. The microhardness of the alloy with 0.35 % Ce is 56.3 higher than that of the alloy without Ce. Studies have shown that the addition of CeO2 to the aluminum matrix composites can effectively improve the mechanical properties of the materials. In the range of 0.5 % – 2.5 %, the mechanical properties of the composites gradually increase with the increase of Ce content. When the Ce content is 2.5 %, the tensile strength and bending strength of the alloy reach 123 MPa and 615.6 MPa [1].

Analogously, other rare earth elements such as Yb, Sm, Er and La have similar effects on the properties of aluminum alloy.

The research, studying on the effect of Bi content on microstructure, mechanical and cutting properties of aluminum alloy bars, showed that the higher the Bi content, the more the number of Bi phase and BiSn eutectic phase, the better the cutting performance of aluminum alloy bars, the shorter the chip length, but the tensile strength and elongation decrease slightly. As shown in figure 1, when the Bi content increases to 1 %, the average length of the aluminum alloy rod chip is 3 mm, the tensile strength is 283.5 MPa, and the elongation is 25.9 %.

![Figure 1. The variation of tensile strength and elongation with the change of Bi content [2]](image)

Therefore, quantitative researches carried out more deeply may be significant to identify the effect of each element. We can also roughly conclude from existing research that changing the content of other elements rationally can improve the performance of aluminum alloy.

2.2. Combined with Graphene

Graphene is relatively new material. It has excellent mechanical properties with Young ’ s modulus up to 1GPa and tensile strength of 130GPa. Also, it has very good thermal conductivity and electrical conductivity. In addition, the chemical properties of graphene are usually stable. If we use some way to combine graphene and aluminum alloy, it will be likely that the properties become better.

At present, there are many studies on the mechanics of aluminum-graphene composites, and great progress has been made. It can be seen from a large number of experimental data that adding a small amount of graphene nanophase in a pure aluminum matrix can not only effectively improve the tensile strength of aluminum matrix composites, but also maintain good ductility. Pure aluminum has high conductivity but low tensile strength while aluminum alloy has higher tensile strength but lower conductivity compared with pure aluminum. At present, the material of high voltage overhead transmission lines is aluminum alloy because it needs high tensile strength. If graphene is used in
electric power transmission, the resistance of the transmission line will be lower so that there will be less energy loss in the transmission section.

The results of an experiment studying the effect of graphene on the microstructure and properties of aluminum alloy show that adding graphene can greatly improve the mechanical properties and electrical conductivity of the alloy. As shown in Table 1 in the same conditions, the tensile strength increased by 21.5% from 95.7 MPa to 116.3 MPa comparing 0Z with 1JZ. The conductivity also had a slight increase while elongation decreased.

| Serial number | Hardness/HV | Electric conductivity %IACS | Tensile strength/MPa | Yield strength/MPa | Elongation |
|---------------|-------------|-----------------------------|----------------------|-------------------|------------|
| 0Z            | 35.8        | 33.2                        | 95.7                 | 73.0              | 26.4%      |
| 1JZ           | 39.1        | 34.7                        | 116.3                | 92.8              | 22.9%      |
| 1P            | 35.9        | 33.2                        | 103.3                | 82.8              | 26.3%      |
| 1Z            | 37.7        | 34.3                        | 108.2                | 85.7              | 25.7%      |
| 2Z            | 38.5        | 34.3                        | 111.2                | 85.8              | 25.4%      |

(Number 0Z contains no graphene while number 1JZ has the highest graphene content)

However, there are many technical problems to be solved. First, it is difficult to obtain graphene with high and stable quality. What is more, research on preparation methods and process parameters needs further improvement and innovation, the existing process methods cannot prepare a large number of mixed powders, which limits the industrialization of aluminum-graphene composites. Finally, the theoretical study of the combination of aluminum alloy and graphene is not deep. The binding, orientation relationship and interfacial reaction mechanism between graphene and aluminum matrix are not clear, which need to be further explored.

### 2.3. Plasma spraying

Another method to improve the properties of aluminum alloy is plasma spraying. It is easy for aluminum alloy to be corroded in alkaline conditions, acidic conditions and chloride conditions. Coating the aluminum alloy with a certain layer can give the alloy some different physical and chemical properties. This technology can increase surface performance to a large extent without changing its internal properties.

Hard AlN phase can be formed on the surface of aluminum alloy by nitrogen ion implantation. After implantation, the surface hardness is about 6 times higher than the base material. And the wear resistance of aluminum alloy increases with the increase of nitrogen injection [4].

Coating a layer of ceramic on the surface of aluminum alloy can make aluminum alloy have corrosion resistance, heat resistance and insulation. The internal combustion engine can also use this method to generate an insulating ceramic layer on some parts of the inner surface of the cylinder, reducing metal heat dissipation, thereby improving efficiency. Plasma spraying process can make most of the metal surface composite technology to obtain very satisfactory results so that they have both metal and ceramic functions. However, when this process is applied to some parts of the engine, spalling occurs, especially on the aluminum alloy.

Adding a bonding transition layer between metals and ceramics can improve the connection strength between the two. Iron, cobalt, nickel or its alloy can be used as transition metals between aluminum and ceramics. In most cases, a good bonding effect can be obtained by using nickel or nickel alloy. Unfortunately, when the engine is running under high horsepower or full load conditions, such ceramic surface, the nickel layer on aluminum fell off, thereby reducing the thermal insulation of low engine. Studies have shown that there is an obvious alumina film between the nickel layer and the aluminum alloy, which acts as a barrier. The existence of alumina film makes the nickel droplets sprayed by plasma beam unable to penetrate the oxide layer and dissolve with aluminum. One of the reasons is that the melting point of alumina is above 2000 °C, and the molten nickel droplet cannot
melt it. Another reason is that the heat of nickel droplets is not enough to melt aluminum, so that the nickel droplets through the oxide film enter the liquid aluminum for mutual dissolution, and the molten nickel droplets remain outside the oxide film on the surface of solid aluminum [5]. Based on this, we might be able to achieve the aim by removing the alumina film on the aluminum alloy surface before coating nickel on aluminum alloy surface. Dissolving alumina film by acid and spraying in oxygen-free conditions might be a method studied in future research.

2.4. The heat treatment of aluminum alloy

There are 4 fundamental technologies for heat treatment which are called quenching, normalizing, tempering and annealing. Generally, after quenching, the metal becomes hard but brittle at the same time, and usually, tempering is required to reduce brittleness. The purpose of annealing is to make the internal structure of metal reach or close to the equilibrium state, and obtain good performance. The effect of normalizing is similar to that of annealing, but the microstructure obtained is finer, which is often used to improve the cutting properties of metals. One experiment mainly studies the effect of the annealing process on the properties of aluminum alloy sheets. The experimental results showed that the sheet before heat treatment has high tensile strength and yield strength. The tensile strength reaches 412 MPa, the yield strength reaches 390 MPa, and the elongation is only 8 %. After annealing at 270 °C and 300 °C, the mechanical properties of the plates changed greatly, and the tensile strength and yield strength decreased significantly, while the elongation increased significantly. When annealed above 300 °C, the tensile strength and yield strength still decreased, and the elongation increased, but the change was not obvious. The tensile strength was maintained at about 300 ~ 310 MPa, the yield strength was about 140 ~ 150 MPa, and the elongation was about 23 % ~ 25 % [6].

Another experiment focused on quenching of aluminum alloy. Rather than using water, a quenching liquid called PAG was used. A large number of practices show that this kind of quenching agent can significantly reduce deformation, reduce residual stress and obtain required strength performance compared with hot water. The objective was mainly to study the influence of quenching agent concentration on the properties of aluminum alloy. The results showed that with the increase of quenching agent concentration, there is a certain amount of change in the ultimate tensile strength and elongation, and the variation range is not large. As shown in figure 2, when the quenching agent concentration is 10%, the tensile strength reaches the maximum and elongation becomes highest when the concentration is 15%. As shown in figure 3, when the concentration is 10%, the tensile strength and elongation reach the maximum value at the same time. From the experiments on the two types of aluminum alloy, we can roughly estimate that when this kind of quenching agent concentration is 10% to 15%, the comprehensive properties of aluminum alloy become the best.

![Figure 2. Tensile properties of 7075 aluminum alloy quenched by different concentrations of quenching agent [7]](image-url)
Figure 3. Tensile properties of 2024 aluminum alloy quenched by different concentrations of quenching agent [7]

3. Conclusion
In short, changing the content of other elements, heat treatment, combination with graphene and plasma spraying are four practical methods to improve the performance of aluminum alloy. Each of the methods has its advantages and limitations. In the future, there need to be more studies on aluminum alloy since it has such a great performance. High performance, high quality, high uniformity, low cost are still the main direction of the development of aluminum alloy new materials and aluminum processing technology [8].

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