Development of the New Material MZ01 with Excellent Wear Resistance and Corrosion Resistance for Twin-Screw Extruder Parts

耐摩耗性と耐腐食性に優れた二軸押出機部材用新材料『MZ01』の開発

Fumiya KUROGI　Katsuya MASHIMA　Yasunori MINAGAWA　Shuji UENO




黒木 史哉　真島 克弥　皆川 泰範　上野 修司

Keywords; wear resistance, corrosion resistance, MZ01, twin-screw extruder parts, impact resistance, lightness

キーワード; 耐摩耗性，耐腐食性，MZ01，二軸押出機部材，耐衝撃性，軽量

Abstract

In twin-screw extruders used for producing high-functionality plastic compounds, the consumption of these parts is becoming serious owing to the increase in a number of hard filler and flame retardants added. We developed a new material, MZ01, using powder metallurgy technology that achieves the long-life of twin-screw extruder parts. The wear resistance and corrosion resistance of MZ01 are much better than those of the conventionally used alloy tool steel SKD11 and powder high-speed steel SKH40. In user evaluation of actual equipment, MZ01 achieved a life span of more than 15 times longer than that of SKD11.

高機能プラスチックコンパウンドの生産に使用される二軸押出機において，硬質フィラー添加量の増加や難燃剤の添加により部材の消耗が深刻化している．我々は粉末冶金技術を用いて二軸押出機用部材の長寿命化を実現する新材料『MZ01』を開発した．『MZ01』の耐摩耗性および耐腐食性は従来使用されてきた合金工具鋼『SKD11』や粉末ハイス『SKH40』と比較してはるかに優れていることが確認された．ユーザーでの実機評価において，『MZ01』は『SKD11』の 15 倍以上の長寿命化を達成することができた．

1. Introduction

1.1 Current state of the high-functionality plastics industry

In recent years, the weight reduction of automobiles has been accelerating, conventional metal materials are being replaced with functional resin materials such as fiber-reinforced plastics and multi-materialization are progressing. Functional resin materials are also widely used in electronic components such as automobile parts and semiconductor encapsulants for 5G technology. Reducing the weight of automobiles and developing IoT technology are trends that will have a major impact on building a sustainable society in the future, accordingly technological innovation is increasingly required.

1.2 Problems in the high-functionality plastics industry

In general, twin-screw extruders are used to produce functional plastics compounds. The parts of this twin-screw extruder wear out due to attack by the hard filler added to the resin and contact between parts. Wear of the parts causes a decrease in production efficiency, contamination of foreign matter into the resin being kneaded and deterioration of kneading quality. Special hard steels are usually applied to the parts. However, there are needs for materials with lower metal contamination and higher wear resistance owing to the increase in the filler loading in recent years. In addition, materials with high corrosion resistance together with wear resistance are required. This is because some additives induce corrosion of screw element parts when adding additives such as phosphoric acid flame retardants to hard filler.

1.3 Adoption of cemented carbide and new problems

Cemented carbide is a sintered alloy mainly consisting of hard tungsten carbide and cobalt as a binder. It is mainly used as a cutting tool for metal processing because it is very hard and has moderate toughness. Furthermore, cemented carbide can control the mechanical properties by the tungsten carbide particle size, proportion of the metal components and trace additives, and it is widely used in wear-resistant applications, such as cutting blades, molds, and rollers.

In many cases, special steels are used as twin-screw extruder parts due to their high wear resistance. However, with the increasing use of hard filler in plastics and interest in reducing metal contamination, materials with higher wear resistance are demanded. Thus, we have had a lineup of screw elements and barrel liners made of cemented carbide, and we have been increasing our track record of adoption of these parts. Photographs of the appearance of alloy tool steel SKD11 and cemented carbide after use in the actual machine to produce a glass-fiber high-filling compound are shown in **Fig. 1**. The life of alloy tool steel that in commonly used with excellent wear resistance is 3 months. On the other hand, the life of cemented carbide is 33 months, more than 10 times longer than that of alloy tool steel.

Although it has been confirmed that cemented carbide has excellent wear resistance through field tests using actual machines, the high specific gravity of cemented carbide is a major issue in its use as screw elements. Cemented carbide parts are about twice as heavy as steel, and twin-screw extruders are designed to mount multiple elements on a cantilevered shaft, which causes the shaft to sag. For this reason, the number of cemented carbide screw elements that can be loaded is limited. Those who have used cemented carbide have requested that light materials be developed to load more screw elements.

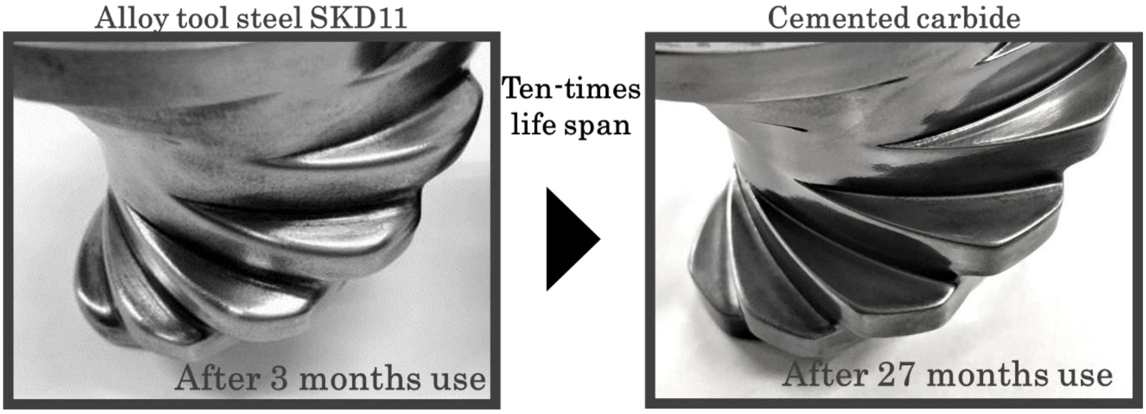

Fig. 1 Photographs of the appearance alloy tool steel SKD11 and cemented carbide after use as the screw element to produce a glass-fiber high- filling compound

2. Development concept of the new material MZ01

Generally, the ceramics and cermet have both wear resistance and light weight. Although both materials have high hardness and excellent wear resistance, they are difficult to apply to screw elements because of their low impact resistance.

The largest difference between cemented carbide and these lightweight materials is that cemented carbide contains high specific gravity tungsten carbide as a hard phase.

We focused on the hard phase and started developing new materials that are light weight and have wear resistance and impact resistance equivalent to cemented carbide by adding various lightweight metal carbides as hard phases. The characteristics of each material are given in **Table 1**, and the concept for developing the new material is shown in **Fig. 2**.

Using technology of controlling structure, additive technology and an alloying process, we developed the new material MZ01.

Table 1 Properties of various materials used for twin-screw extruder parts

Material	**Ceramic** (silicon nitride Si_3N_4)	**Cemented carbide** (VM50 equivalent)	**Alloy tool steel** (SKD11)
Specific gravity	3.3	14.0	7.7
Vickers hardness	1,700	1,150	720
Charpy impact value (J/cm^2)	3.7	14.1	20.0

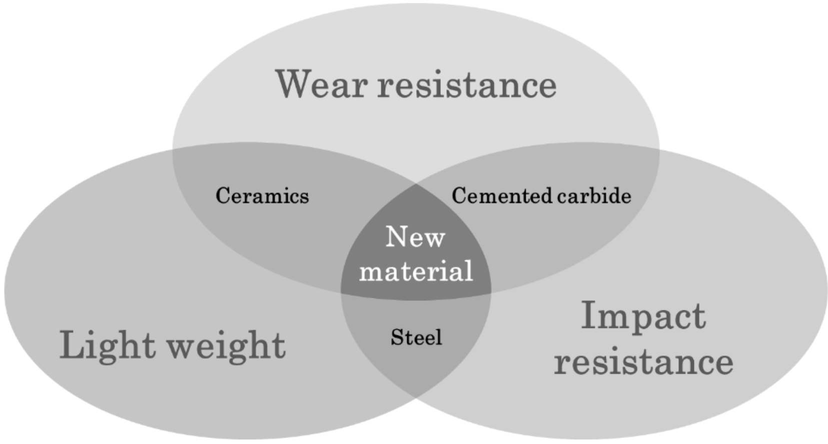

Fig. 2 Development concept of the new material

3. Characteristics of MZ01

3.1 Material properties of MZ01

A comparison of various properties of MZ01 and other materials are shown in **Table 2**. In general, there is a trade-off relationship between the hardness and toughness of materials, therefore it is difficult to achieve both wear resistance, which is correlated with the hardness, and impact resistance, which is affected by the toughness. MZ01 maintains high hardness and high toughness due to its unique structure. In addition, the magnetic properties and volume resistivity necessary to remove chips when the extruder parts are chipped have been controlled to a practical level.

Table 2 Characteristics of the new material and other materials

		New material (MZ01)	Alloy tool steel (SKD11)	Powder high-speed steel (SKH40)	Cemented carbide (VM50)	Nickel-based alloy (Inconel 600)
Specific gravity		7.1	7.7	8.1	14.0	8.4
Vickers hardness		1150	720	910	1150	180
Young's modulus	(GPa)	330	210	230	540	210
Charpy impact value	(J/cm^2)*	4.4	21.3	23.0	6.3	unmeasured
Saturation magnetization	($\times 10^{-7}$ Tm^3/kg)	510	2160	2180	250	8

*Charpy impact specimen shape: 10R notch formed

3.2 Wear resistance of MZ01

The wear resistance evaluation of rubber wheel tests for each material are shown in **Fig. 3**. The wear resistance of each material was compared with that of alloy tool steel based on the wear volume before and after the test. Wear resistance of MZ01 showed 4.7 times higher than that of alloy tool steel and 1.3 times higher than that of cemented carbide (equivalent to VM50). This cemented carbide was confirmed to have more than 10 times longer life than that of alloy tool steel in the aforementioned actual machine.

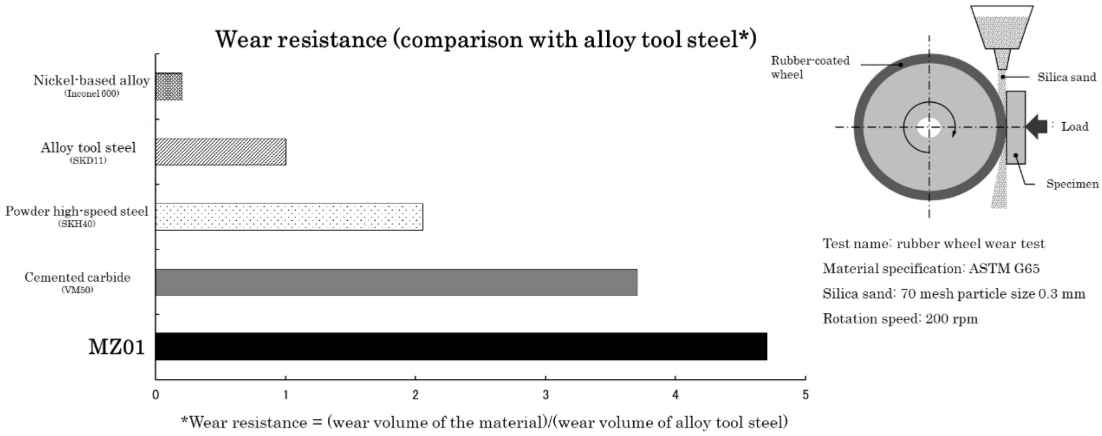

Fig. 3 Wear test results of each material

3.3 Corrosion resistance of MZ01

Fig. 4 shows the corrosion test results of each material in 10% aqueous solution of various acids and photographs of the appearance of the test pieces after the corrosion tests. This figure shows the volumetric residual rate of each material after 24 h of immersion in the acid solution. MZ01 showed excellent corrosion resistance to any acid solution. It was confirmed that MZ01 has a clear advantage over alloy tool steel and powder high-speed steel, which are widely used as twin-screw extruder parts, and it is also applicable to kneading highly corrosive materials.

During the promotion of MZ01 products, we received many inquiries about the corrosion resistance of MZ01 compared with that of nickel-based alloys with excellent corrosion resistance. As shown in **Fig. 4**, MZ01 has slightly lower corrosion resistance than Inconel 600, a nickel-based alloy. However, Ni-based alloys are materials with low wear resistance, so it cannot be expected to extend the life of twin-screw extruder parts. In order to extend the life of the parts, it is important that the material has both wear resistance and corrosion resistance. Based on results of the twin screw extruder parts life, we visualized the performance positioning of each material in terms of the wear resistance and corrosion resistance. As an example, the corrosion resistance and wear resistance performance positioning against phosphoric acid is shown in **Fig. 5**. Generally, the importance of wear resistance or corrosion resistance will vary depending on the user's usage conditions, so this positioning should be used as a reference when selecting materials against phosphoric acid corrosion and wear. We also have accumulated data on the wear and corrosion tests for each material We will provide the data upon request.

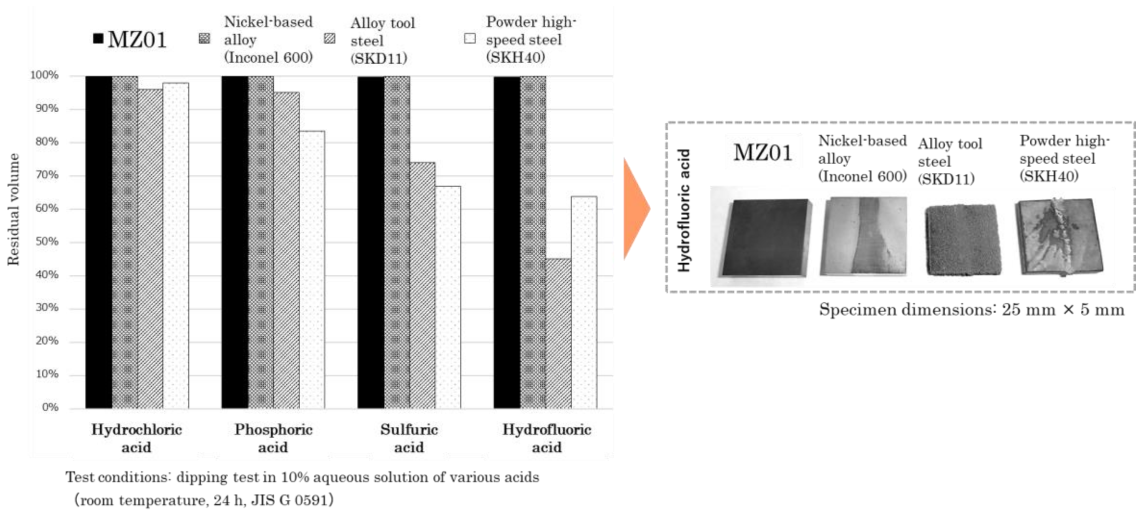

Fig. 4 Corrosion test results of each material

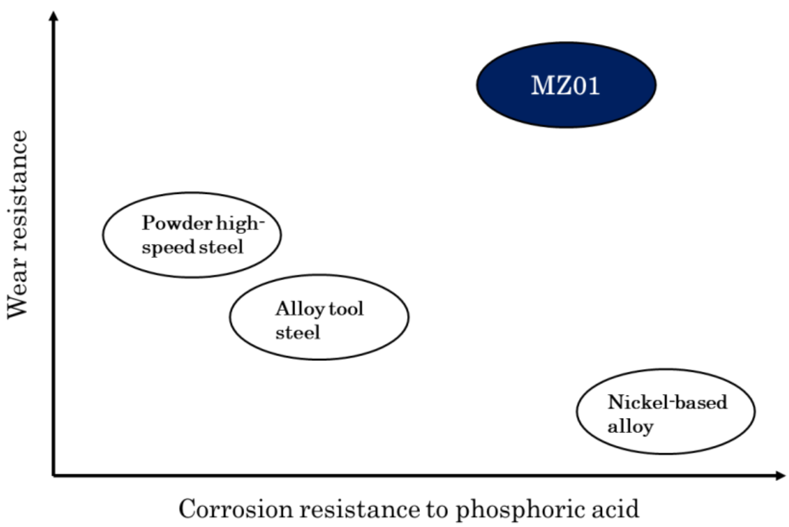

Fig. 5 Performance positioning of each material against phosphoric acid

3.4 Actual performance of MZ01

Photographs of the alloy tool steel and MZ01 screw elements after use in the production of a glass-fiber high-filling compound are shown in **Fig. 6**. Comparing the degree of wear of the parts based on their shape and weight, it was confirmed that the wear resistance of MZ01 was 15 times higher than that of alloy tool steel. The MZ01 screw element is still in continuous use. These results confirmed that MZ01 has wear resistance equal to or higher than that of cemented carbide and its specific gravity is half that of cemented carbide. The MZ01 material has been adopted for the production of hard-filler high-filling compounds, there are many demands from our customers.

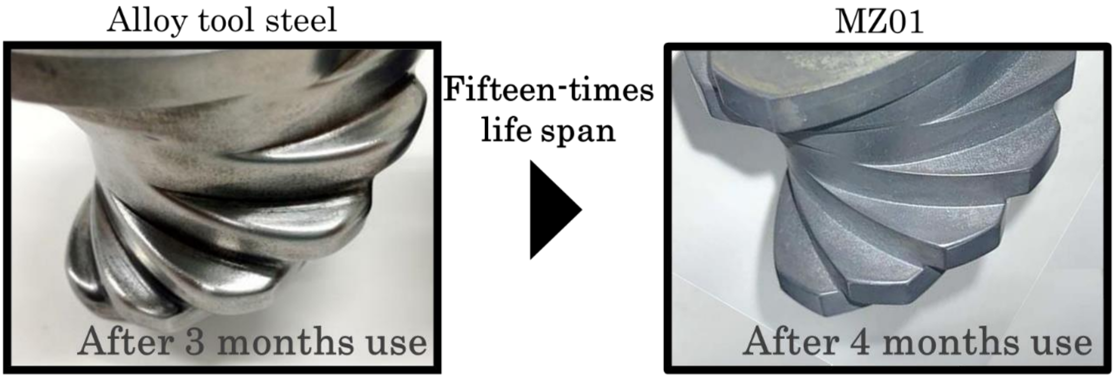

Fig. 6 Photographs of the appearance of alloy tool steel and MZ01 as the screw element after use to prepare a glass-fiber high-filling compound

4. Conclusions

Some radar charts comparing the characteristics of MZ01 with those of other materials in four aspects, wear resistance, corrosion resistance, impact resistance, and light weight are shown in **Fig. 7**. The high specific gravity of cemented carbide is a disadvantage, and it is unsuitable for this application. Nickel-based alloys have high corrosion resistance, but their wear resistance is low, making it difficult to extend the lifespan of twin-screw extruder parts. We succeeded in developing MZ01, which has high wear resistance and corrosion resistance while compensating for the shortcomings of these existing materials. As mentioned above, MZ01 has a sufficient level of magnetic and electrical properties for removing from the compound, and it is a new material that combines the elements necessary for the parts of twin-screw extruders with good balance.

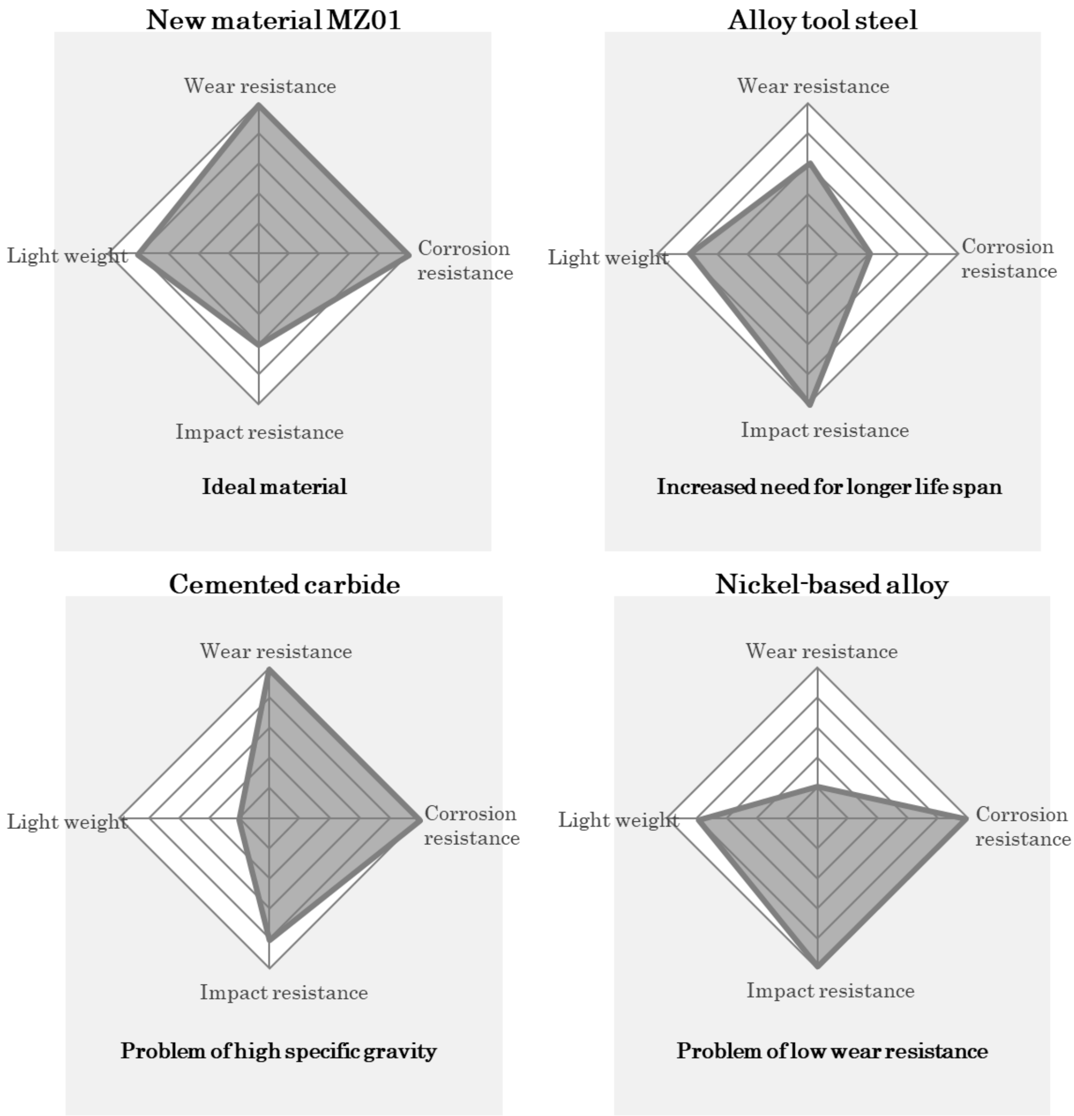

Fig. 7 Comparison of the characteristics of the four materials