Technical Development of Thixomolding Machine and its Future Prospects

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―Synopsis―

Thixomolding, the injection molding technology for magnesium alloys, was developed by The Dow Chemical Company (USA). The process is similar to the plastics injection molding. By thixomolding, chip material of magnesium alloy is melt and stirred with screw in the barrel and the molten magnesium alloy is injected into the die to mold the parts. JSW has built not only the thixomolding machine but also total production system for mass production of magnesium alloy parts since 1992. Up to today, more than 500 molding machines have been shipped all over the world and are being used for mass production of various magnesium alloy products.

As the global warming has become evident year by year, CO_2 emissions will be restricted more strictly from now on. Because of this background, the weight reduction of automobiles becomes an urgent social need, and magnesium alloy products are expected to be increasingly important as a means of weight saving. Being superior in terms of safety and environmental protection, Thixomolding will meet the social requirement better than the conventional die-casting technology for producing magnesium alloy parts.

We describe a short history of the development of Thixomolding, and its technical evolutions during this 20 years, as well as the future progress we foresee.

1. Preface

100 years has passed since magnesium, the lightest practical metal, began being used as an industrial light metal material. Deformation processing of magnesium alloy during cooling had been difficult and conventional casting processes (die casting, sand mold casting, etc.) had been used for production. The Japan Steel Works, Ltd. (JSW) introduced a Thixomolding, which is one variant of casting, in 1992. We have been developing, manufacturing, and selling these molding machines ever since. Up until now, we have successfully sold a total of nearly 510 units. Throughout this time, molding machines have added improvements to match the needs of the market with the JLM-MG, -MGII, -MGIIe models.

The application of thixomolding method started with components such as industrial video camera bodies and expanded use to the IT field from digital cameras and mobile telephones to notebook computers. Market recognition of the many superior characteristics offered by magnesium was in the backdrop of this expansion. These characteristics included a lighter weight as well as better recyclability and electromagnetic wave shielding. Lighter, thinner, and smaller components in-line with societal needs was one factor.

Even in the automotive field, lighter vehicle bodies are imperative as a solution to problems that included energy savings and environmental issues. The superior toughness and thermal resistance of magnesium alloy has been gaining greater attention year after year.

As shown in Figure 1, the demand forecast for raw magnesium in the future shows dramatic growth in both the IT and automotive fields due to weight-saving needs. This demand for raw magnesium is expected to more than double in 2020 compared to 2013.

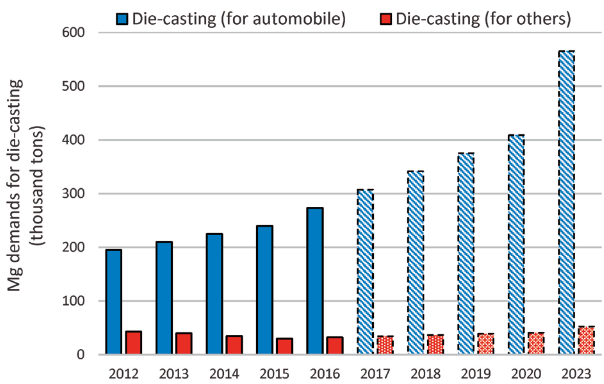

Figure 1 Demand forecast for raw magnesium in the future[3)]

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This report introduces the adoption of thixomolding technology, the history of the molding machine development, characteristics of each generation molding machine, and the role of MG Precision Co., Ltd. (MGP), our subsidiary engaged in our magnesium molding business, in addition to new technological development. In conclusion, this report also describes the future potential of thixomolding.

2. Development History

2.1 The Early Days

The development of thixomolding technology began with the discovery of the thixotropy phenomenon of semi-solid metal at the Massachusetts Institute of Technology (MIT) in 1971. David Spencer[1], a student at MIT at the time, was who stumbled upon the phenomenon where the viscosity appeared to decrease if a molten alloy was agitated in a semi-solid state. The molten alloy also would return to its original viscosity when the agitation stopped. Thixotropy is one physical phenomenon where the viscosity of a fluid possesses reversible changes under shearing stress. Thanks to Flemings[2] and his team, this phenomena assisted in the development of a metal fabrication process known as rheocasting.

Injection molding technology has evolved as a molding technology for plastics. However, The Dow Chemical Company and the Battelle Memorial Institute began to pursue the application of this technology for the molding of magnesium alloy in the mid-1970s. JSW introduced this technology in 1992 in an effort to develop a practical machine. In 1994, we completed our first generation prototype with 4410 kN clamping force. (Photo 1) We learned a great amount using this prototype, including the verification of operation technology and the mastering of the mold technology.

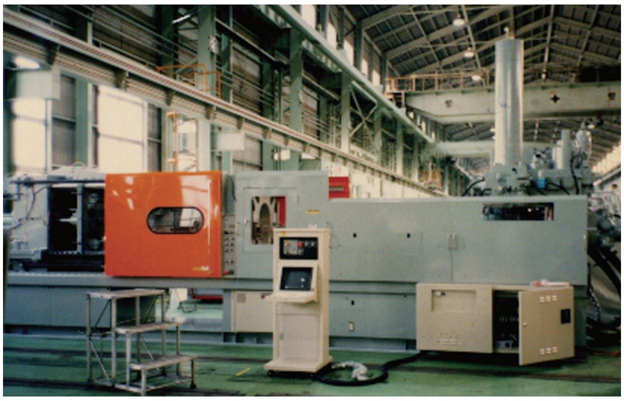

Photo 1 JSW first generation prototype (with 4410 kN clamping force)

Moreover, injection molding of magnesium alloy gained traction and became accepted in the market for reasons founded in the circumstances outlined below.

Specifically, the harmful effects of global warming caused by fossil-fuel consumption had become well-known, and there was an outcry for energy savings in every industrial field. As a measure to address energy-saving issues, the automotive industry as well as others recognized the benefits of lighter weight transportation equipment and explored alternative lighter metals such as aluminum alloy and resin for structures conventionally made primarily from steel and iron. Magnesium alloy was one viable candidate gaining attention.

The greatest advantage of magnesium is the light weight with a specific gravity of roughly 1.8, which is equivalent to one-fourth the weight of ferrous materials or two-thirds the weight of aluminum alloy. Conventionally, components produced via die-casting required a large amount of molten alloy always be available. Sulfur hexafluoride (SF6) was a special gas used to prevent the molten alloy from combusting. However, SF6 gas has a large environmental impact that contributes to global warming if emitted into the atmosphere. These effects are said to be more than 20,000 times more that of carbon dioxide, and industries avoid its use.

Injection molding machines on the other hand do not expose molten alloys to the air due to their structural nature and, therefore, do not require the use of any SF6 gas. Alloys are only in a molten state inside of the barrels in injection molding machines, which requires dramatically less thermal energy to melt and maintain alloys than in the die-casting process. Molding magnesium alloy via injection molding is greatly favored for these reasons from a perspective of global environmental preservation. Even in terms of labor, injection molding can provide a safer and more work-friendly environment than die-casting processes.

2.2 Prototype for Mastering Practical Application in Technology

JSW is a manufacturer of plastic processing machinery. We have accumulated years of technology and know-how in the development and manufacture of plastic injection molding machines, yet thixomolding requires completely different elemental technology even though injection molding is the same. The biggest difference is of course the material to mold. The temperature to melt plastic is 200 to 300°C while the melting point for magnesium alloy is around 600°C. Materials of many of the components such as the screw and barrel of the molding machines required high-level thermal resistance to respond to this temperature difference.

The mold technology also needed to be different because the solidification behavior between plastic and magnesium alloy is also completely different after injection into a mold. We learned much about a wide variety of technology from the die-casting field, such as the material quality and structure of molds, casting plans, and the selection of releasing agents.

There was one issue of safety that cannot be avoided when handling magnesium alloy. As is well known, magnesium is an active metal that easily combusts if in contact with the air in a molten state or causes dust explosions if scattered in the air as fine powder. We incorporated safety measures into our design unlike anything in plastic injection molding machines to create a machine able to eliminate hazardous materials and provide safety to our customers.

In addition, the length of the process from molding to the completion as a component was another aspect we had to learn in the development for practical application in technology. In plastic injection molding, plastic components are often complete once plastic is injected into the mold. Conversely, magnesium alloy requires post processing after molding from cutting (trimming) burrs and runners, machining such as threads, surface polishing, and then finishing. More often than not, surface processing, coating, and other similar processes are also necessary. We went beyond our stance of a traditional manufacturer of injection molding machines and have been building efficient manufacturing processes to provide to our customers by understanding all of these processes while working with companies dedicated to each individual process.

2.3 Completion as a Practical Machine

JSW shipped the JLM450-MG with 4410 kN of clamping force as the first commercial machine in 1994 after the above sequence of events. Thereafter, we have added various improvements and expanded these machines in an expansion that should be called an alternation of generations. Our third generation of models, MGIIe, is offered in the market today. This is described in more detail in Chapter 3, but several technological improvements were necessary to bring a practical machine to fruition.

First was the structure of the barrel. In a design adopting American technology, the structure integrated a cobalt-based abrasion resistant alloy sleeve on the interior surface of a barrel made with a nickel-base thermal resistant alloy. We used nickel-based alloy for the base material of the barrel because no ferrous material could endure a barrel heating temperature between 600 to 630°C. The design required a sleeve made from a different material though because a nickel-based alloy would easily corrode and dissolve molten magnesium alloy.

However, this type of complex structure increases manufacturing costs, and the nickel-based alloy has a lower thermal conductivity than steel among other performance issues. We collaborated with our Muroran Research Laboratory, which has a long history in the research and development of ferrous materials, to develop and equip an actual machine with special thermal resistant steel able to tolerate heating used up to 630°C. This innovation eliminated the need of a sleeve to protect the interior surface and also improved the thermal conductivity to heighten stability of operation as a molding machine. Concurrently, we also transitioned the material of the screw to our proprietary thermal resistant material from the material used at the time the technology was adopted. Screws and barrels made from this unique JSW material have been continually used since.

In this way, we have expanded and popularized molding machines in the market by incorporating our unique technologies. The next section specifically introduces the track record of that progress.

3. Progress of Molding Machines

As described above, we are striving to advance molding machines every day to respond to the needs of the market. This advancement can be categorized into the following three generations if we take a broad view of the progress up until now.

3.1 First Generation: JLM-MG Series (1995-)

This was the first series released to the market in 1995 as a commercial machine with six models boasting clamping force from 735 kN to 8330 kN. In Japan, we generated interest in thixomolding and participated as a molding business to distinguish ourselves from the many plastic molders offering the same injection molding technology. From 1996, many small- and medium-size models were introduced for portable MD players and the parts for small household appliances.

We then even delivered a large-size model overseas to a Taiwanese company for the production of notebook computer bodies. Moreover, this technology made a strong impact on the industry when Japanese companies sold the world's thinnest computer products thanks to parts molded using thixomolding. The application of magnesium alloy for all four parts of the body sparked the "silver computer" boom in the computer industry.

In 1999, the flip telephone was released with an exterior body made from magnesium alloy. More strength was necessary in the hinge area and frame structure as the liquid crystal screens advanced in color and size. The application of magnesium alloy became the standard to propel the popularization of thixomolding machines.

3.2 Second Generation: JLM-MGII Series (2002-)

The MGII was released into the market in 2002 as the successor of the first generation MG machine. This series offered a design that pursued the following improvements in productivity:

(1) Better yield rate
(2) Greater molding stability
(3) Reduced molding cycle
(4) Greater potential for thinner products
(5) Multi-cavity molding

Large-capacity servo valves were used to realize these improvements, which succeeded in increasing the maximum injection speed of conventional machines from 3.8 m/s to 5.0 m/s.

We introduced a flood feed (FF) screw designed as a result of magnesium chip feed simulations inside of the barrel. Conventionally, the supply of materials to the barrel had been adjusted by the feeder, but adjusting the amount of the supply was no longer necessary with an FF screw. This innovation not only simplified the molding conditions but also reduced the measurement (recovery) time while also dramatically improving molding stability.

In terms of clamping, the designs heightened the rigidity of platens 40% through FEM analysis results and reduced the deflection at the center of the platen. We also implemented a switch-over circuit for the variable pump for the first time in the world to facilitate high-speed opening and closing of the mold.

In 2003, major mobile telephone companies worldwide established bases in China and expanded production of magnesium alloy components using thixomolding.

3.3 Third Generation: JLM-MGIIe Series (2006-)

The MGIIe series was released into the market in 2006 with the main objective of offering more compact machines than the MGII series. Photo 2 shows the external view of the JLM850MGIIe machine (8330 kN clamping force). The benefits the designs for this series aimed to be emphasized are as follows:

(1) Lowering initial costs
(2) Reducing running costs
(3) Improving molding stability
(4) Improving workability and maintainability

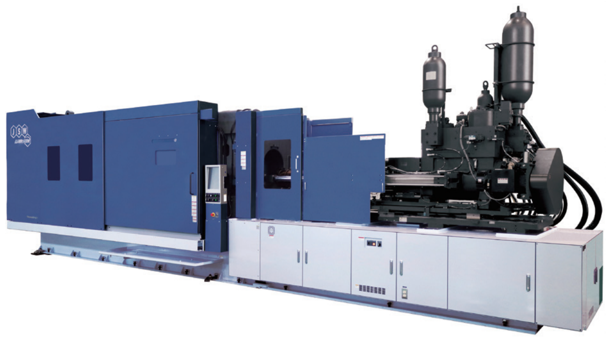

Photo 2 External view of the JLM850MGIIe machine (8330 kN clamping force)

We were able to succeed in providing these benefits by flexibly responding to diverse needs through lighter injection pistons and simplified hydraulic piping in addition to the unitization of both the injection and clamping mechanisms.

4. MG Precision Co., Ltd.

4.1 Establishing MG Precision Co., Ltd.

JSW established MG Precision Co., Ltd. (Hereinafter "MGP") as a full-fledge mass production molding company in 1996 for magnesium alloy products via the world's first thixomolding within the Hiroshima Plant. The purpose of establishing MGP was to verify production using thixomolding, and creating a foundation in all production processes from molding to coating of magnesium alloy components and widely expand the production technology to thixomolding users.

4.2 Shift in MGP Business

Expectations of end users for magnesium alloy was high at the time MGP was established, but the production of parts was limited to enclosures for items such as professional video cameras with a low production volume in order to avoid complex post processes such as machining and burr processing after injection molding. Thereafter, the world's thinnest exterior body for an MD Walkman with a thickness of 0.65 mm was ordered to realize the first mass production of a consumer component with a large production volume.

Prototypes and mass production orders continued for the external casings and frames of mobile telephones (Photo 3) from 2000. Mass production of these components rapidly increased due to demand for light, thin, and highly rigid parts following the accelerated standardization and enhancement of functionality of mobile phones. Barrel apparatuses and shot blast devices were introduced and applied to mass production to eliminate the complexity of post-processing faced up until then to increase production efficiency. Moreover, in addition to trimming presses that had been used to remove burrs, MGP also developed special presses for deburring and finishing. The main force of production was the 280-ton machine with fundamentally two to four molding cavities. The guidelines of the designs for proposals of molds for molding, chemical treatment and coating processes were established through these production activities.

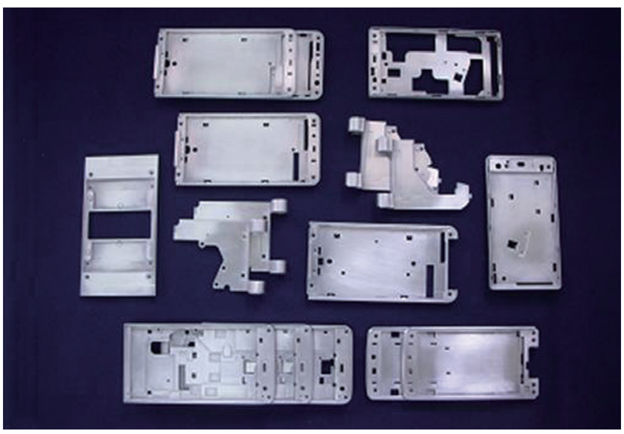

Photo 3 External casings and frames of mobile telephones

In 2002, orders for prototypes and mass production of exterior bodies as well as internal components for high-class SLR camera (Photo 4) began. Many of the camera components are larger and have more complex geometry than mobile telephone components. Another level of advanced production technology was needed due to the strict requirement for accurate geometry and MGP responded to those needs. The driving force of production for these components is also the 280-ton machine with fundamentally one molding cavity. The quality of the thixomolded products has been highly praised by customers. Even today, numerous camera components and industrial video camera components derived from those camera components are still in production. In recent years, MGP introduced image inspection equipment able to automatically detect the need for pad printing on the visible surface as well as flaws in machined holes to both realize better productivity and quality.

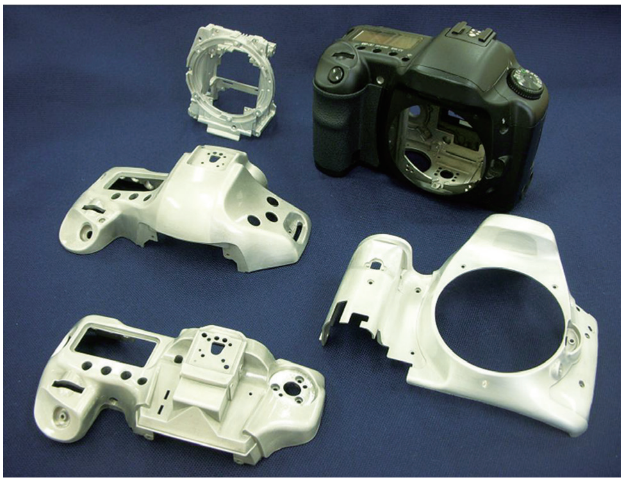

Photo 4 Components for SLR camera

Since 2005, production has been underway of external bodies for notebook computers, which had a minimal number of order models. The geometry for these components largely differed from the components in mobile telephones and cameras in production up until then. The projected area of the molded product was large and the product was thin. MGP developed new production technology for large thin products because a 650-ton machine was required for molding rather than a 280-ton machine, which had been the main production machine (described later). This production technology recently realized the production of an external casing with a 0.45 mm thickness for a 12.1-inch tablet (Photo 5).

Photo 5 Components for tablet

In 2011, the company successfully entered into the automotive parts industry (Photo 6 to 10). The thixomolding process is suitable for automobile parts due to the ability to mold magnesium alloy into complex geometry as single parts for the light weight, high rigidity and high heat radiation without largely impacting the environment. The production technology for large and complex components cultivated in the mass production of mobile telephones, camera components and notebook computer bodies produced primarily with the 650-ton machine was incorporated for ongoing stable production. Thanks to this track-record in mass production and the increasing needs for lighter weight vehicles, the industry has a greater tendency to put inquiries for new vehicle components as well as make repeat orders for subsequent vehicle models. The performance in mass production of vehicle parts has played a part in the standardization of magnesium alloy components in the automotive industry.

Today, JSW and MGP are working together to further advance the development of production technology to reach an even greater level of production efficiency for magnesium alloy components through thixomolding.

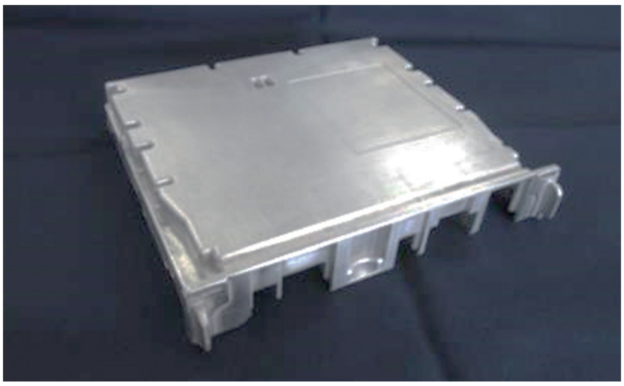

Photo 6 Components for automobiles (ECU case)

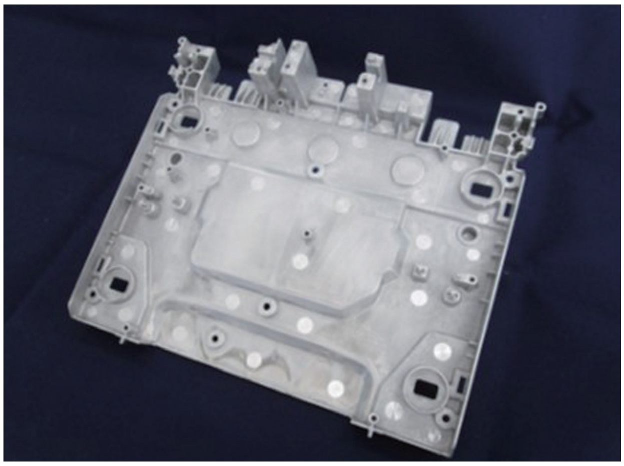

Photo 7 Components for automobiles (LCD chassis)

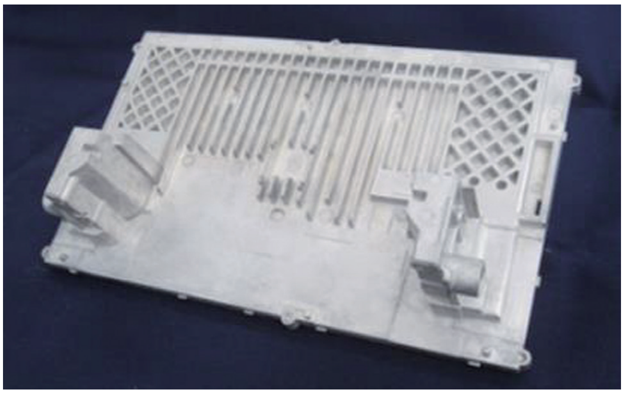

Photo 8 Components for automobiles
(Car navigation system LCD frame)

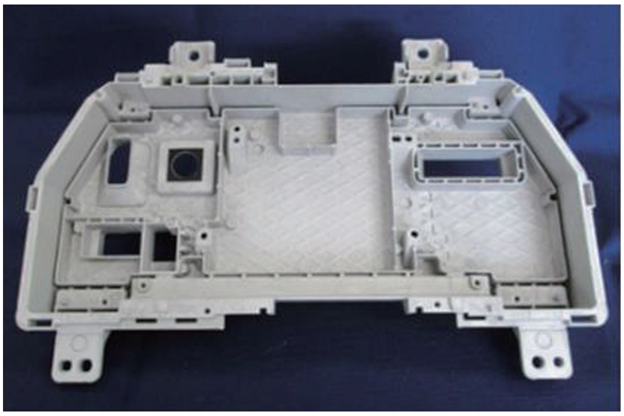

Photo 9 Components for automobiles (Display meter case)

Photo 10 Components for automobiles (internal part)

5. Technological Development Since 2007

As described in Chapter 3, JSW has continually endeavored to develop new molding machines and molding processes since releasing the JLM-MG machine to the market in 1995. Much of the success up to 2007 has been outlined by Kengo Takeya and his team[4]. Therefore, this report will discuss the activities thereafter.

5.1 Development of Large-size Magnesium Alloy Injection Molding Machines

The current models in the MGIIe series pursue lighter, more compact machines with a lower part count to bring the price of these molding machines to a level able to compete with die-casting machines while sustaining or improving the molding performance of the MGII in addition to fundamentally modifying the hydraulic circuit and injection drive unit. This series has been able to meet the needs of small- and medium-size components of IT products such as smartphones, tablet terminals and notebook computers.

MGIIe became a series of four models with the respective clamping forces of 2750 kN (JLM280-MGIIe), 4410 kN (JLM450-MGIIe), 6370 kN (JLM650-MGIIe) and 8330 kN (JLM850-MGIIe). Among these models, JLM850-MGIIe (Photo 2) is the model primarily used in the production of thin enclosures such as that for tablet terminals and 15-inch notebook computers. We have sold a total of 510 machines since implementing the thixomolding method to our technology in 1993 to start sales of full-fledged magnesium alloy thixomolding machines in 1997. This model is in fact our best seller and consists of roughly 200 units of those sales.

In recent years, needs for larger, thinner and lighter IT products is accelerating with future trends increasing demand for a large-size notebook computer that has an LCD screen of 17 or more inches. Table 1 shows an example for specification of a large-size notebook computer body. JLM650-MGIIe is used in the mass production of the thin molded body for this size of enclosure.

Additionally, American and European automotive manufacturers in particular are accelerating the trend of magnesium applications for vehicle weight reduction aimed at better eco-friendliness of emissions and improved fuel efficiency as well as for on-board electronic enclosures such as vehicle navigation systems and gauges, and for lighter heat sinks due to the transition of headlights to LED lights. Greater demand for small- and medium-size components is expected to grow in the large notebook computer and automotive fields. An example of product specifications with a molding weight under 2,000 g is shown in Table 2. These products are produced today with the JLM650-MGIIe, but the field of magnesium alloy parts is showing a strong tendency toward larger sizes.

Up until that point, the first generation machine with a clamping force of 8330 kN (JLM850-MG) was the biggest large-scale production machine. This model had been used for the production of the seat back frame at Japanese automotive manufacturers, but an equivalently large-size machine was in demand for the MGIIe series. Due to this demand, we have developed and released a model (JLM850-MGIIe) with 8330 kN of clamping force to the market.

Table 1 Example of specification of a large-size notebook computer body

LCD size	15 inch (present)	17 inch	19 inch
Thickness, mm	0.8≦	1.0≦	1.2≦
Outer dimension, mm	230×340	260×380	290×420
Product weight, g	130≦	200≦	290≦
Molding weight, g	320≦	500≦	730≦

Table 2 Example of product specifications of medium-or small size (less than 2,000 g molding weight)

Product name	LCD meter frame	LED heat sink	Door inner panel
Thickness, mm	1.5	1.5≦	2.0
Outer dimension, mm	120×600	ϕ260	200×500
Product weight, g	450	1200	700
Molding weight, g	800	1400	1000

5.2 Parting Agent Atomization Technology

The work environment of thixomolding is more favorable than die-casting because it does not have large melting equipment. However, thixomolding cannot be said to be more favorable than the work environment of plastic molding. The major reason for this is the atomization of the releasing agent. A releasing agent needs to be sprayed in every shot externally onto the surface of the metal mold for the purpose of improving the mold release properties and preventing seizure in the metal mold whether thixomolding or die-casting. This spray results in water vapor and releasing agent mist, which contaminates the work environment.

Moreover, variations in the capacity of deposit for the releasing agent not only greatly influences the quality of molded pieces but also results in reducing the lifespan of a mold due to the large thermal load that occurs on the mold surface as a result of water evaporation. JSW is advancing research and development into a minimal releasing agent application method to address the problems associated with these releasing agents.

The greatest feature of a minimal releasing agent application method is the ability to atomize the releasing agent as a stock agent, not diluted in water. Minimal application of the releasing agent offers the minimum amount of releasing agent to be sprayed into the mold to eliminate the need for waste liquid treatment in addition to effectively improving the work environment by preventing the excess releasing agent from spreading outside of the mold. This not only eliminates the need for air blowers while reducing the molding cycle but also provides advantages that include no decrease in the surface temperature of the mold due to the releasing agent, better fluidity of the molten magnesium alloy, and greater dimensional precision of thin molded pieces. Figure 2 shows an example adopting the minimal releasing agent application method. This example raises the metal mold temperature to 50°C and makes thin molds of 0.4 mm or less possible in addition to eliminating the need to fill in deficiencies with putty to correct flaws after an article is molded.

We have introduced and are presently conducting practical tests of a minimal releasing agent application system that uses a spray nozzle with the capability to atomize only a minimal amount of releasing agent as well as a minimal releasing agent supply unit. Advantages of a minimal releasing agent application system have become clear for the mass production of actual products.

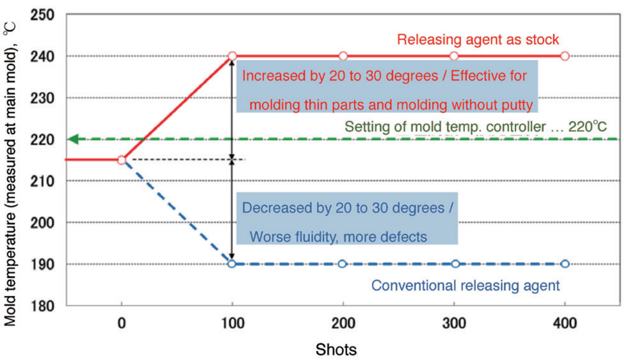

Figure 2 Keeping the mold temperature by the minimal releasing agent application method

5.3 *Stepping Up to the Challenge of Diversifying Materials*

The various molding examples described up to this point have all utilized AZ91D (JIS: MD1D) as the type of alloy. This alloy is a magnesium alloy composed of roughly 9% AI, 0.7% Zn, and 0.2% Mn. This is an extremely excellent alloy widely used as a material in die casting and injection molding that balances properties such as castability, strength, and corrosion resistance. There are many other alloys developed as magnesium alloys and standardized, however, the only alloy really in use practically is AZ91D.

Injection molding is a technology competing with die casting, but molding of materials unique to each process is feasible because injection molding and die casting are completely different processes. JSW is also aiming to diversify molding materials in line with the features of the process. We are testing several new materials related to magnesium alloy for injection molding. [5, 6, 7] This report introduces two examples of materials that we have recently worked with.

First is Mg-Zn based alloy[7]. As LED lighting has started to become standard in recent years, magnesium alloy molded products have begun to be considered as heat sinks. The MGP has even produced heat sinks of large LED lighting as described previously, but the material used was AZ91D. The thermal conductivity of heat sinks is vital, however, the thermal conductivity of AZ91D is almost less than half that of ADC12 aluminum alloy, which is made by die-casting, for example. Conversely, Mg-Zn alloy is known to have a composition range that easily cracks upon solidification after molding[8], but it has a high thermal conductivity comparable to ADC12.

There are a variety of explanations about the mechanism causing solidification cracking, but molding products in a mold at low temperatures has the potential to limit this cracking. We have tested moldings with injection molding that allows for low-temperature molding. The two types of alloy used in these moldings were Mg-5mass%Zn and Mg-10mass%Zn. The molded bodies were 100 × 200 × 2 mm flat plates. As a result of various attempts, we have been able to succeed in molding products from Mg-10mass%Zn alloy with almost no cracking.

Figure 3 shows the measurement results for the thermal conductivity of the Mg-Zn based alloy that was molded. This is approximately twice that of

AZ91D, which is a universal magnesium alloy, and the values are as good as or better than ADC12 aluminum alloy. We can expect the realization of an even lighter LED heat sink with superior thermal conductivity than ever before with the use of this type of alloy.

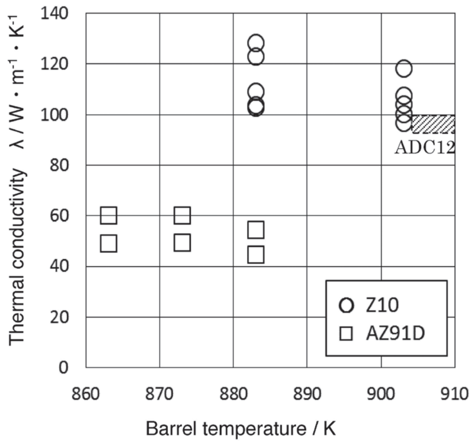

Figure 3 measurement results of the thermal conductivity

The second example improves strength and limits casting defects by applying carbon powder to the surface of the magnesium alloy chips used as a raw material.

Carbon additives are known to be effective in the crystal grain refinement of magnesium alloy[9]. However, carbon additives are difficult to use directly because the carbon itself makes wetting of the molten magnesium alloy difficult. Research groups primarily at the Industrial Technology Center of Okayama Prefecture and STU Co., Ltd. have discovered that applying carbon to the surface of the raw alloy chips for injection molding, and then supplying these chips to the molding machine for molding in that state has shown a phenomenon that demonstrates the effectiveness of the carbon additives (product name "UH alloy")[10].

The phenomenon that was discovered included (1) refinement of crystal grains, (2) improved strength achieved from that refinement, and (3) a reduction in fine molding defects (shrinkage cavities). The mechanisms causing the phenomenon are not entirely clear, but carbon introduced to a molten alloy interacts with the AI in the AZ91D and forms an aluminum carbide. This is thought to result in the refinement of crystal grains because the carbon acts as a karyogenesis site of the solidification core. Moreover, the carbon applied to the surface of the chips acts as a solid lubricant and reduces friction between the chips in the molding machine, which is thought to be effective in changing the filling condition of the chips.

Figure 4 shows a comparison of the tensile strength between molded bodies (flat plate with a thickness of 2 mm) made using AZ91D and AZ91D-UH. The improved strength can be seen clearly. Figure 5 shows the Electron Back Scatter Diffraction Patterns (EBSD) of AM60B and AM60B-UH. The refinement of the crystal grains due to the carbon additive can clearly be seen.

Figure 6 shows the molding of the same molded body (notebook computer enclosure) using AZ91D and AZ91D-UH and compares the state of internal flaws in the boss section. The fewer defects in the molded body made using the UH material are obvious.

A small amount of carbon additives has effectively improved a variety of aspects of moldings. Strictly speaking, the UH material is more appropriately seen as a material for the pre-processing of an existing alloy rather than a new type of alloy, but the material leverages the characteristics of the injection molding process. We have great hope for the broad practical application of the UH material in the future.

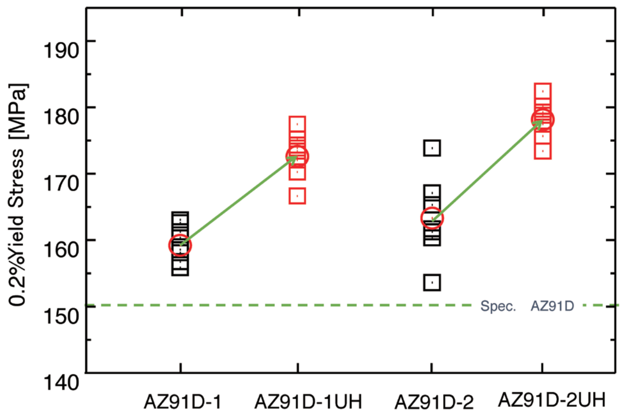

Figure 4 Comparison of the tensile strength between molded bodies made of AZ91D and AZ91D-UH

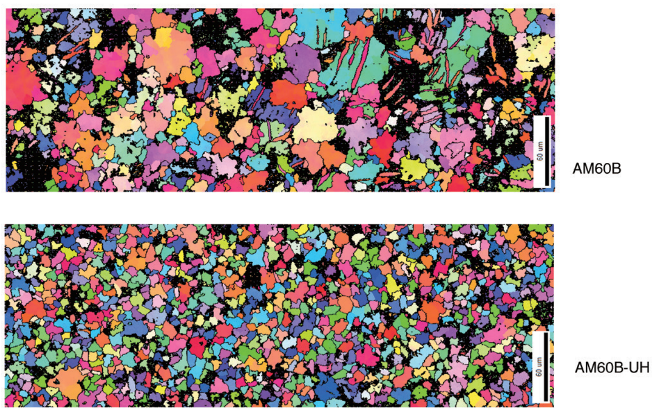

Figure 5 Refinement of the crystal grains of AM60B (by EBSD)

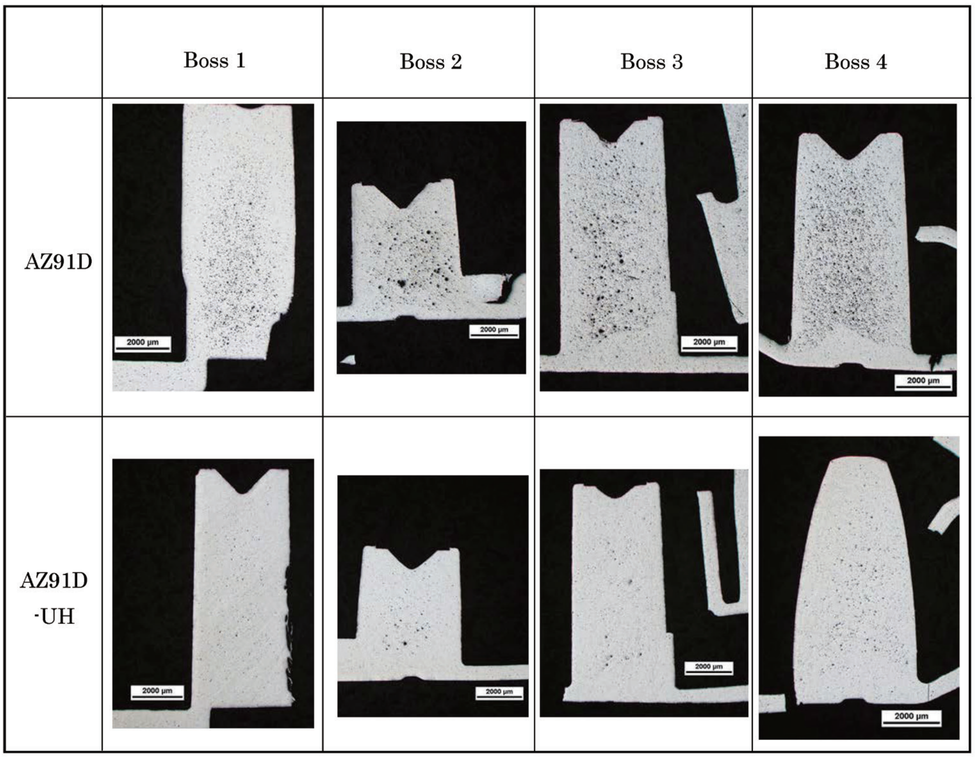

Figure 6 Examples of less inner defects in the boss section by UH material

6. Future Expansion

The above has summarized the evolution of thixomolding technology for 20 odd years. Magnesium alloy has garnered great attention in a wide range of industries as a light metal material. JSW has continued the evolution of molding machines, molding technology and other production systems that support magnesium alloy. Today, several hundred JSW thixomolding machines are being used in mass production worldwide, and these machines have become known as a standard in magnesium alloy production technology.

In the future, the social requirements for magnesium alloy as an industrial material are clearly higher than ever from the perspectives of energy savings and global environmental preservation. Moreover, expansion to the aviation and railway fields that have always been adverse to "flammable" materials are also beginning to consider practical use of magnesium alloy.

We are actively aiming to advance molding technologies as thixomolding machines and systems in the future to respond to these needs.

The development of various technologies for thixomolding has advanced with focus on the production of thin molded articles emphasizing the exterior because the components have been most often adopted for electronics and mobile electronic devices. However, in recent years, the technological innovation is also aiming in a direction to pursue the application to even thicker structural components due to market demand. To achieve these objectives, it is important not only to improve molding technology but also to innovate operation technology in systems that include mold technologies and peripheral equipment. In terms of molding machines, advancement focuses on points such as the ability to mold larger products, the reduction of power consumption and improvements of both hard and soft aspects of the technology to facilitate even easier operation.

Our intention is to promote the supply of magnesium alloy components to a wide range of fields by accumulating the ingenuity and innovation above accumulated over the last 20 years to further advance thixomolding technologies.

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