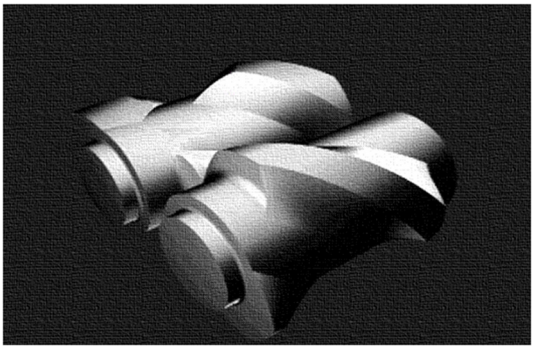
Advanced Intermeshing Mixers for Energy Saving and Reduction of Environmental Impact



TAKASHI MORIBE*1

In recent years, there has been growing demand for mixers compatible with new materials and high-quality mixing in rubber product industries including fuel efficient tires. With excellent mixing (distribution and dispersion) characteristics and cooling capacity, Mitsubishi's new mixer with a unique intermeshing rotor system has been attracting attention to its attainment of high-quality rubber, which was difficult in the past, as well as to its contribution to the improvement of energy conservation and productivity. In addition, the new mixer can improve wear resistance against high-hardness fillers including silica due to the application of durable surface finishing technologies. A number of the new mixers are in service in domestic and foreign rubber and tire manufacturers.

1. Introduction

In response to global environmental problems and resource and energy issues, the automotive and other industries have been energetically promoting the development of technologies for the reduction of CO_2 emissions. Also in the rubber industry, technological development of fuel efficient tires has been attracting attention in recent years, and in order to develop functional rubber consisting of new materials and composite materials, there has been growing importance placed on environmental load reduction technologies including not only raw materials and compound design, but also production and manufacturing processes.

In the rubber industry, internal mixers have been widely used. Because the functional characteristics of rubber products depend largely on the mixing process, different mixing facilities are used depending on the compound, required quality, type of production, etc. Internal mixers are classified into the tangential type and the intermeshing type depending on the rotor structure. In general, the production of tire rubber, for which productivity is important, uses mainly tangential mixers, while the production of industrial rubber, which requires strict quality, mainly utilizes intermeshing mixers. In recent years, however, when changes in raw materials – in particular the introduction of silica compound used for fuel efficient tires – have been implemented, conventional mixers have become unable to satisfy the required performance.

In order to meet such needs, MHI has developed the new MR-EX mixer equipped with a new intermeshing rotor system, and has been promoting compatibility with increasingly advanced mixing technologies.

2. Structure and function of mixer

2.1 Structure of internal mixer

As shown in **Figure 1**, internal mixers are classified into the mixer type and the kneader type depending on their structural and functional features. Generally, the mixer type requires high durability compatible with high-load mixing and has the benefit of excellent production capacity due to high-capacity and high-speed mixing. Although mixed rubber compound is fast-discharged by the drop door system and therefore the cycle time between batches can be reduced, the establishment of a frame is necessary and would result in increased installation cost.

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On the other hand, the kneader type requires moderate discharge time because the discharge of the rubber compound uses the chamber tilting system, but the installation of the main unit is easy and a low-cost configuration can be attained. The kneader type has the benefit of high maintainability due to easy access to the mixing chamber, but it is not suitable for high-load mixing because the pressing force of the floating weight is relatively small due to the large width of the floating weight fitting in the chamber. Typically, the mixer type is used for small variety and large quantity production, and the kneader type is used for large variety and small quantity production.

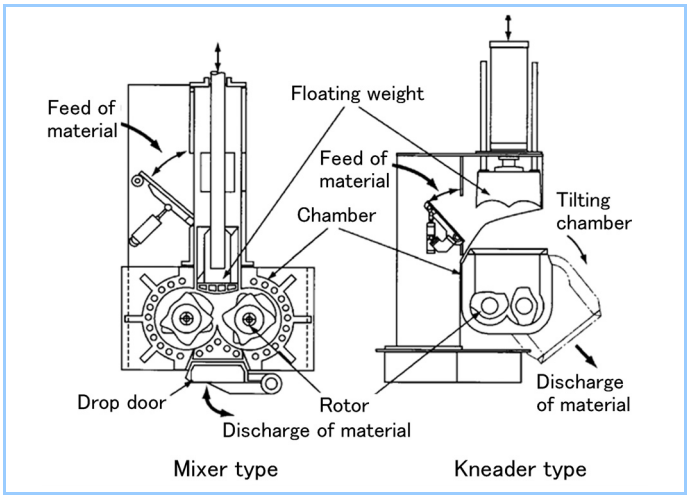
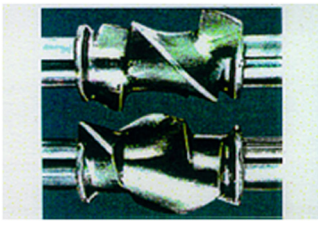
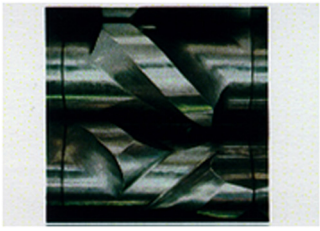
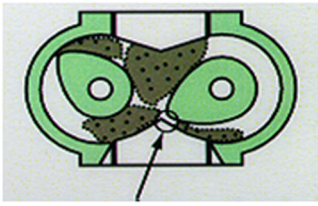
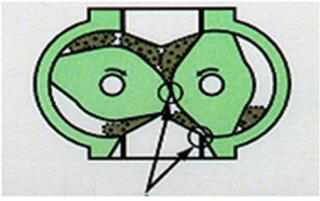


Figure 1 Structure of internal mixer

2.2 Function of mixing rotor

The two mixing rotors in a mixer serve as its heart. The design of the rotor has a significant influence on mixer performance. **Table 1** compares rotor types and their functions.

Table 1 Rotor types and functions

Rotor type		Tangential rotor	Intermeshing rotor
Rotor shape			
Mixing mechanism		 (1) Between rotor and chamber wall	 (1) Between rotor and chamber wall (2) Between rotor and rotor
Function	Shearing	◎Excellent	◎Excellent
	Distribution	○Good	◎Excellent
	Intake	◎Excellent	○Good
	Cooling	△Acceptable	◎Excellent

(1) Tangential rotor

Mixing is performed between the rotor and the chamber wall. The mixing time is short because the rotor clearance between the two rotors is large and the intake of raw material is generally fast. However, because the operation depends mainly on intense shearing at the tip of the rotors, there is difficulty in distribution and cooling. This causes fast temperature increases during the mixing of rubber compound and therefore the careful management of rubber

temperature is necessary. In the mixing of high-heat generating compounds, the mixed rubber compound is discharged and cooled when the allowable temperature limit is reached, and then mixing is repeated until the desired rubber properties are satisfied.

(2) Intermeshing rotor

An intermeshing mixer has a 2-shaft rotor system and the rotor of each shaft meshes with the other. Mixing is performed not only between the rotor and the chamber wall, but also between the two rotors. Because the rotor clearance between the rotors is small, the intake of raw material is weaker than that of the tangential rotor and generally the cycle time is increased. However, when higher shearing force between the rotors is applied, the properties of the rubber can be improved. In addition, due to excellent distribution and cooling performance, the intermeshing rotor system is particularly suitable for temperature-sensitive compounds and high-quality mixing of various kinds of rubber.

3. Features of Mitsubishi intermeshing mixers

3.1 Aim

There is strong demand for the capability to obtain the favorable distribution and dispersion of raw material rubber or filler and the consistent quality of products, as well as the attainment of short mixing time and high productivity. However, these demands include opposing issues. The improvement of quality and productivity requires high-speed mixing with intense shearing force, but at the same time such mixing causes an increase in rubber temperature due to the heat generated by shearing. Therefore cooling and re-milling processes are needed for the prevention of material deterioration and the necessary quality is reached by repeated mixing. In addition, increased use of compounds including high-hardness fillers such as silica has resulted in a salient problem, with early wear and loss of hardened surfaces of the mixer components including the mixing rotors. As a result, the improvement of the durability and wear resistance of the mixer is necessary.

On the basis of the above fact, MHI has developed the new MR-EX intermeshing mixer in order to meet diversifying needs including the improvement of quality and mixing stage reduction, which was difficult with conventional tangential rotor systems.

3.2 Rotor structure

Figure 2 shows the structure of MHI's intermeshing rotor. This rotor system is a conjugated system that combines the benefits of both conventional tangential and intermeshing rotor systems and has the features noted below.

(1) The three wings of the intermeshing rotor design employ a reverse arrangement of the four-wing tangential rotor system to improve fluidity and intake.

(2) Proper fluctuation of clearance is applied between the rotors to improve shearing and intake performances.

(3) A 2-piece structure consisting of the rotor wing and the rotor shaft is employed. In the rotor wing, coolant circulates in a spiral manner to improve the rotor cooling effect, even at the tip of the wing.

(4) The rotor surface finish is a high-hardness alloy coating that has favorable corrosion and wear resistance and improved durability.

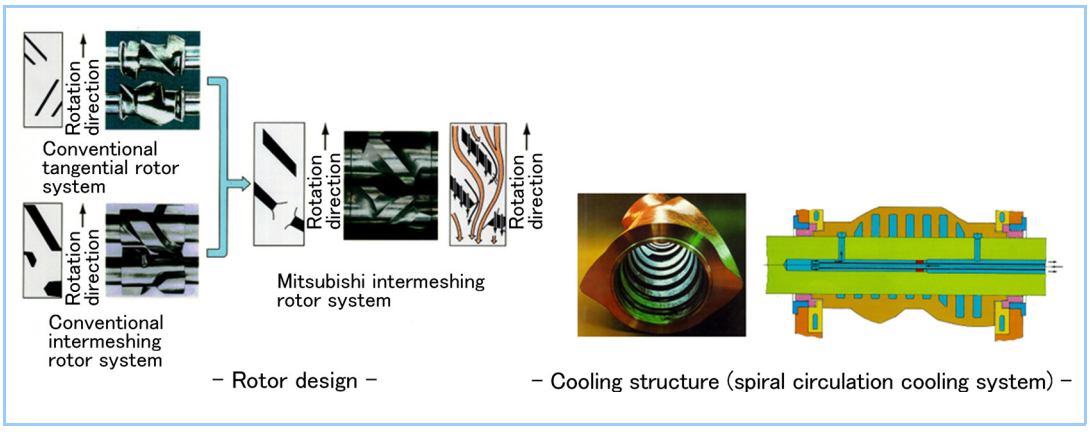


Figure 2 Structure of Mitsubishi intermeshing rotor system

4. Rubber mixing characteristics

4.1 Comparison between tangential and intermeshing rotor systems

Figure 3 compares the results of performance tests of the tangential and intermeshing mixers, focusing on the discharge temperature in rubber mixing. Because the intermeshing mixer has good cooling capability, the discharge temperature of the rubber is low. The margin for the addition of mixing energy (unit work) in consideration of the maximum temperature of the rubber is large, and therefore filler dispersion is improved. For the kneader type, the intermeshing system has a lower rate of temperature increase in comparison with the conventional tangential kneader type. This results in the improvement of rubber properties[1]. The results indicate mixing characteristics that have high distribution and dispersion capabilities.

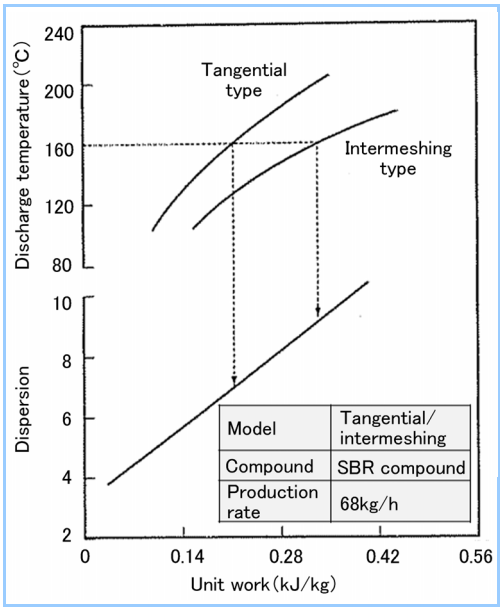


Figure 3 Comparison of rubber mixing performance

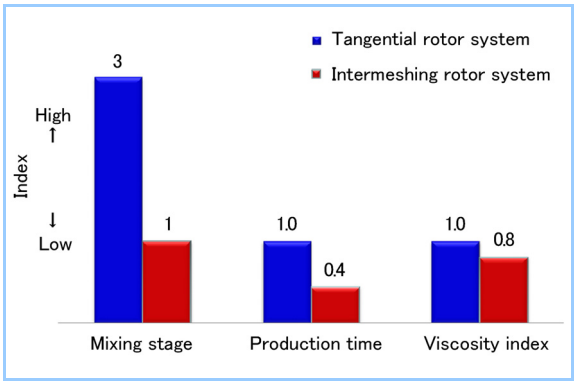


Figure 4 Case example of productivity improvement

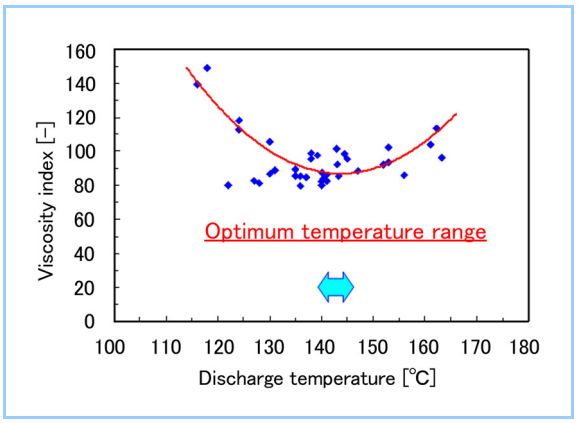


Figure 5 Thermal behavior of silica compound rubber

4.2 Improvement of productivity

In the past, the productivity of intermeshing rotor systems was considered to be lower than tangential rotor systems. However, it is expected that intermeshing systems can utilize their advantages to improve productivity due to a reduction in mixing stages, which is difficult for tangential systems. **Figure 4** shows an example of productivity improvement with an intermeshing rotor system. In this example, the introduction of an intermeshing system has reduced the number of mixing stages (from three to one) and the production time. In addition, mixing quality has also been improved due to performance enhancement from reducing the viscosity of the mixed rubber.

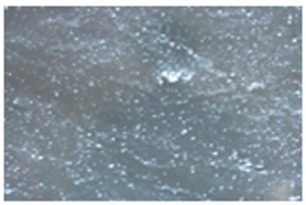
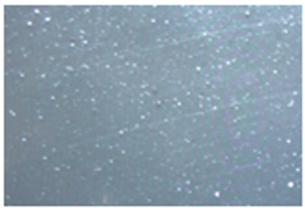
Intermeshing rotor systems are used mainly for the production of industrial rubber. In recent years, however, they have been increasingly introduced into the production of tire rubber. In the tire industry, multi-path mixing, where many large-capacity tangential mixers are used on multiple lines, was widely used. However, an increasing number of intermeshing mixers have been introduced in order to improve the quality of tires and productivity. Such intermeshing mixers contribute to being able to break away from conventional mixing processes and the improvement of productivity.

4.3 Application to reactive mixing

In the tire industry, among environmental load reduction technologies, the development of fuel efficient tires that reduce rolling resistance and improve fuel consumption is being worked on energetically. For that purpose, the raw material has been shifting quickly from conventional carbon black compound to silica compound. Due to such a shift of compounds, the need for a mixer that can control the temperatures and chemical reactions specific to silica compound, in addition to conventionally important shearing capability and dispersion, has increased; especially one that can serve as a reactor.

With silica compound, mixing temperature largely affects the rubber properties as shown in **Figure 5** and there exists a proper range of mixing temperatures(2). MHI's MR-EX mixer is equipped with a new intermeshing rotor (type EX7) and attains further performance improvement in comparison with conventional intermeshing rotors (type E). **Table 2** compares the mixing capabilities of the conventional intermeshing rotor (type E) and the new rotor (type EX7) for silica compound for the production of tire treads. Under the same mixing conditions, the EX7 rotor, even with its lower mixing energy (unit work), creates lower viscosity and improves product formability. At the same time, it also has an excellent mixing effect that improves the strength and quality of products due to the enhancement of silica dispersion. It is expected that such mixing efficiency enhancement will result in an energy conservation effect.

Table 2 Comparison of mixing performance for silica compound rubber

Rotor type	Conventional intermeshing (type E)	New intermeshing (type EX7)
Mixing time	5 minutes	5 minutes
Mixing energy*1	0.73kWh/kg	0.66kWh/kg
Viscosity index*2	87.4	86.4
Silica dispersion*3	X=4.6 	X=6.8 

*1 Energy required for mixing per unit weight of rubber (unit work)
*2 Unvulcanized rubber viscosity (formability index of rubber product): Low (high formability) <-> High (low formability)
*3 Evaluation of silica dispersion on cut sample: 1 (poor dispersion) < X < 10 (good dispersion)

4.4 Improvement of durability

Conventional mixers use welding or chrome plating for the surface hardening of rotors. To deal with increasing high-hardness fillers such as silica compound, MHI has developed durable rotors coated with high-hardness alloy(3). **Figure 6** compares conventional chrome plating and the new surface finish technology. The new surface finish results in higher adhesive strength of the rotor base material and attains higher durability in comparison with conventional chrome plating. At the same time, it enhances wear resistance and coating thickness, and therefore wear life is expected to be nearly quadrupled.

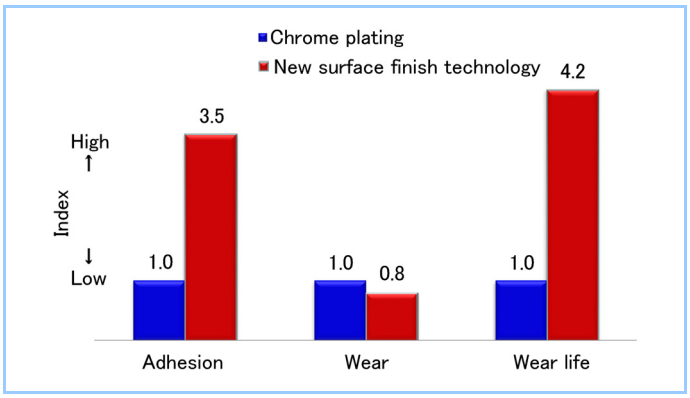


Figure 6 Evaluation of durability

5. Conclusions

In the recent situation where a fast response to global environmental conservation and resource saving is necessary, expectations for technical innovation have also risen in the rubber industry. MHI has developed the new MR-EX mixer equipped with a new intermeshing rotor system. Its excellent mixing characteristics enable mixing stage reduction and the improvement of quality, which were difficult in the past. At the same time, the improvement of energy conservation and productivity is also attained. In addition, it is expected that the introduction of durable rotors will extend service life, as well as contribute to energy conservation and a reduction of environmental burden. MHI is willing to continuously develop mixing technologies and enhance functions to satisfy further diversifying customer needs.

References

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