Newly Developed Large Size Continuous Mixer (LCM-IM)

Kazuo YAMAGUCHI[*1], Yoshinori KURODA[*1], Toru OKADA[*2]
[*1] Plastics Processing Machinery Department, Industrial Machinery Division, Machinery Business
[*2] Mechanical Engineering Research Laboratory, Technical Development Group

A new generation continuous mixer has been developed to cope with the advancement of bi-modal high-density polyethylene (HDPE), which is more difficult to mix. Basic mixing experiments were carried out to confirm that the new continuous mixer, which has been developed on the basis of a new mixing theory, effectively eliminates the gels of the bi-modal HDPE film and exhibits mixing performance superior to that of conventional continuous mixers. Furthermore, a new technique for measuring the action force of mixing has been developed. This technique was used to obtain data, which was analyzed by a newly established analysis method to confirm the mechanical reliability of the new continuous mixer.

Introduction

A large mixer, such as Kobe Steel's LCM (**Fig. 1**), used for primary granulation, must melt and mix powder-like resin polymerized in a reactor in the upstream of the resin production process and homogeneously blend additives, etc., as required. Meanwhile, in recent years, bi-modal high-density polyethylene (HDPE) resins with favorable durability, strength and excellent formability are being actively developed.[1)] Some of these newly developed HDPE resins are difficult to mix due to the difficulty of homogenizing the polymer components in their raw powder.

In order to cope with such newly developed bi-modal HDPE resins, Kobe Steel has extended the conventional design theory of rotor shape, which plays a central role in the mixing operation, and employed intermeshing rotors to achieve a successful mixing performance superior to that of the conventional rotors.

Since the reaction force received by the intermeshing rotors during mixing was unknown, the company developed a method to measure it accurately. This has made it possible to use the actual measurement of the reaction force in the design, ensuring the reliability of the mixer employing intermeshing rotors.

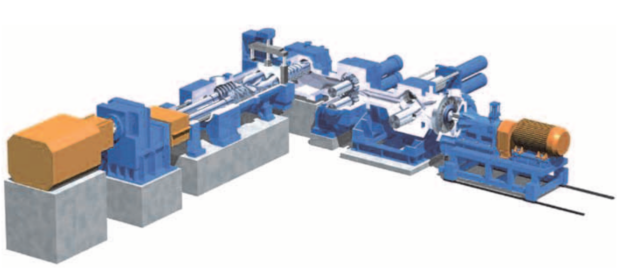

Fig. 1 Large continuous resin mixer, LCM-H

1. Development of mixing rotors

A procedure was adopted in which a two-dimensional model test apparatus was used first to pursue the cross-sectional shape of a rotor that can achieve high mixing quality with less energy, and then the resulting cross-sectional shape was applied to a continuous mixer.

1.1 Mixing theory

The dispersion of gel (agglomeration of undispersed polymer) is driven by the fluid force, exerting shearing and stretching actions, caused by the resin flow created by the mixing blade. Conventionally, Kobe Steel evaluated the mixing performance on the basis of the shear stress the material receives as it passes near the tip of a mixing blade and the number of times the material receives the shear stress.[2)] As for conventionally shaped rotors, the company focused on increasing the shear stress and the number of times that tip-passing occurred to ensure the mixing quality of bi-modal HDPE resin, which has been developed in recent years.

For the production machine, this means decreasing the production volume to increase the residence time and increase the frequency of tip-passing, or reducing the tip clearance to provide higher shear stress. Such an attempt, however, may result in the problems of increased energy consumption, and deterioration of resin due to excessively high temperature. Furthermore, a larger size mixer is required to secure the production volume.

In designing the cross-sectional shape of the mixing blade for the new continuous mixer, the emphasis was put on the mixing action of stretching, in addition to that of shearing, to attain energy efficiency such that the reduction rate of the gel is maximized for the energy provided.

In this way, the development goal for the new continuous mixer was set to secure production volume with the size of a conventional machine and achieve quality using the smallest possible amount of energy.

1.2 Method for evaluating mixing

For pipe grade HDPE, used for gas piping, etc., the "white spots" that appear upon mixing and dispersing carbon were regarded as gel, and their size (hereinafter referred to as "ISO rating") and quantity (as represented by white spot area, hereinafter referred to as "WSA") were evaluated. **Fig. 2** shows an example of photomicrographs containing gel.

1.3 Evaluation of rotor cross-sectional shape on two-dimensional model

1.3.1 Experimental method

A two-dimensional (2D) model test apparatus was used to evaluate the cross-sectional shapes of rotors. This apparatus performs mixing experiments simulating a two-dimensional cross-section of a continuous mixer (**Fig. 3**). The degree of meshing between two rotors is set for two types of rotors, a tangential type and intermeshing type. Fifteen types of rotor cross-sectional shapes (**Table 1**) were prepared using the tip clearance and the inclination angle (front angle) of the working surface as the main parameters.[1)]

These rotors were installed on the 2D model test apparatus, which was charged with powder material and carbon black powder for coloration. After the mixing operation was performed for a prescribed time, the melted and mixed material was taken out to make comparisons of the ISO rating and WSA.

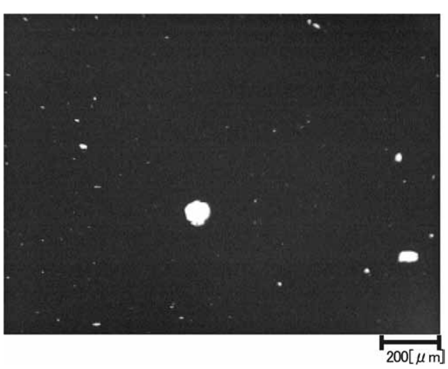

Fig. 2 Gel (white spots) in polyethylene compound pellet colored with carbon black

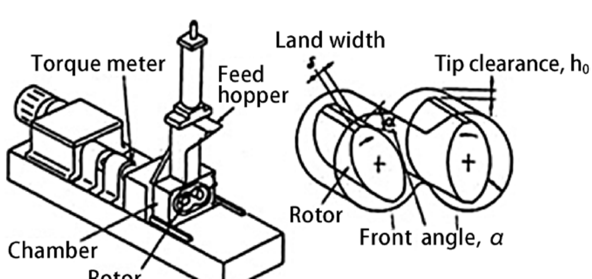

Fig. 3 2D model test apparatus

1.3.2 Experimental results

In general, the mixing action and mixing energy are roughly in proportion, and the greater the energy, the greater the degree of mixing that is accomplished. In the experimental results, the rotor achieving superior mixing with a small energy input is regarded as exhibiting high efficiency and excellent performance.

Therefore, to make a comparison, the dispersion ability of each rotor shape was normalized by the specific energy, which is the value obtained by dividing the total energy required for mixing by the amount of material to be processed. **Fig. 4** shows how the WSA values of mixtures are reduced during the mixing time in the 2D model test apparatus in the cases of the 15F rotor shape, which exhibits the most favorable mixing performance with a low energy input among the standard tangential-type rotors, and the 15Q rotor shape, which exhibits the most favorable performance among the intermeshing rotors.

In a tangential-type rotor, mixing is driven mainly by the shearing action occurring in the wedge-shaped space between the inner wall of the

Table 1 Cross-sectional shapes of rotors for 2D model test

		Front angle			Land width	New concept shape
		Small	STD	Large	Large	
Tip clearance	Narrow	Rotor # 15A	Rotor # 15B	Rotor # 15C	Rotor # 15L	Rotor # 15P
	STD	Rotor # 15E	Rotor # 15F [STD]	Rotor # 15G	Rotor # 15M	Rotor # 15Q
	Wide	Rotor # 15H	Rotor # 15J	Rotor # 15K	Rotor # 15N	Rotor # 15R

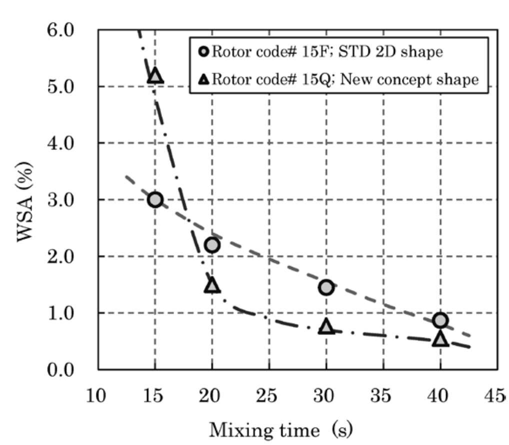

Fig. 4 Results of mixing experiment using 2D model test apparatus

chamber and the rotor tip. Among the standard tangential-type rotors, the 15F rotor shape is believed to provide the mixture with shearing action most efficiently.

Among the intermeshing rotors, the 15Q rotor shape showed an even more favorable performance than the 15F shape. That is, a favorable WSA value was achieved within a shorter mixing time. In the case of intermeshing rotors, it is believed that a complicated flow field is generated near the center part where the rotor meshes, which causes stretching action in the flow, in addition to the shear action between the inner wall of the conventional chamber and the rotor tip. In a stretching stress field, the gel is dispersed by energy smaller than that in a shearing stress field. This is considered to be the reason for the more efficient gel dispersion.[3)]

1.4 Application to continuous mixer

A rotor for continuous mixers comprises a screw part for sending material downstream and a rotor part for providing mixing action. In general, the rotor part consists of a pair of threads each having a relatively long pitch, one for forwarding the material and the other for returning the material.

A study was conducted to determine the optimum combination of the length and angle of the threads for forwarding and returning the material, including the combinations for the conventional tangential rotors, to select candidate cross-sectional shapes of rotors to be applied to the continuous machine.

Various combination experiments have revealed that optimal mixing performance is achieved by a two-stage mixing-rotor configuration that follows the LCM-H mixing concept, in which a tangential-type rotor is applied to the first mixing part, and an intermeshing type rotor is applied to the second mixing part. The conventional LCM-H and newly developed LCM-IM were used to mix and granulate film-grade bi-modal HDPE, and the pellets thus prepared were formed into films. The total area of the gel in the film was plotted against the specific energy input (SEI) required for mixing, as shown in **Fig. 5**.

Fig. 6 schematically compares the rotor construction of the newly developed LCM-IM with that of the conventional LCM-H. The newly developed LCM-IM employs the 15F cross-section for the first stage and the 15Q cross-section for the second stage.[4)]

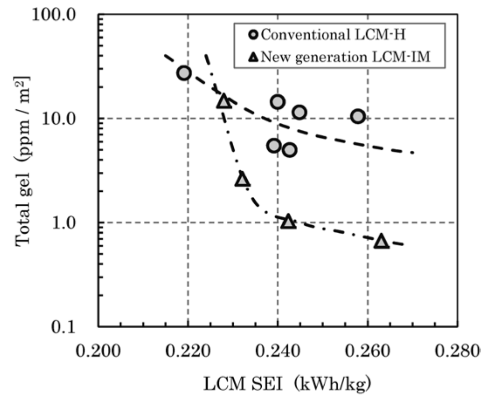

Fig. 5 Results of mixing experiment using continuous mixer

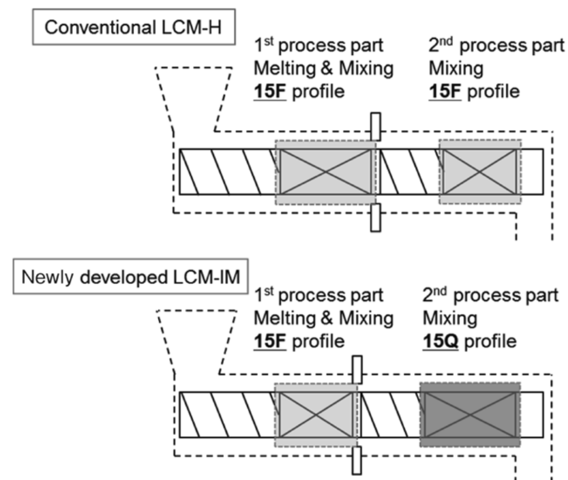

Fig. 6 Comparison of rotor arrangements between conventional LCM-H and newly developed LCM-IM

2. Measurement of mixing force

Mixing force is an important factor in designing LCM. In LCM, the force required for melting and mixing resin is provided as the mechanical action force of a rotating rotor. The rotor receives the reaction force. Unlike bi-axial extruders, this reaction force is supported by the bearings holding the rotor. As a result, the rotor becomes subjected to repeated bending stress, which can cause fatigue fracture if the stress exceeds the allowable limit.

The mixing force has been measured every time the shape was changed since the beginning of the LCM development. Intermeshing rotors, however, are unprecedented and unknown. Hence, the mixing force was measured in more detail before adopting the new intermeshing rotors.

2.1 Mixing force measuring system

The new LCM employs two-stage mixing, and each of its mixing rotors comprises a first mixing part and a second mixing part. The newly developed load-measuring system includes strain gauges to independently measure the force acting on each mixing part.

Each rotor is supported by three bearings, i.e., two bearings, both supporting the drive end, and one bearing supporting the water end. Therefore, the deflection due to mixing force constitutes a statically indeterminate beam problem, and the superposition principle can be applied in a model where the mixing force acts on two locations. **Fig. 7** shows the relationship between the strain gauge location and load location for the rotor supporting method.

Each of the strain values at the drive end (DE) and the water end (WE) is a composite value of the strain due to the mixing forces acting in the first mixing part and the second mixing part. Hence, the loads are applied separately in advance in the first mixing part and the second mixing part to measure the strain values and to determine the linear coefficients, $\alpha 1$, $\alpha 2$, $\beta 1$ and $\beta 2$, of the force-strain relationship. The relationship between the mixing force and measured strain is expressed by the following simultaneous equations:

$$\varepsilon \mathrm{DE} = \alpha 1 \cdot \mathrm{F1} + \alpha 2 \cdot \mathrm{F2}$$

$$\varepsilon \mathrm{WE} = \beta 1 \cdot \mathrm{F1} + \beta 2 \cdot \mathrm{F2},$$

wherein F1 and F2 are the mixing force acting in the first mixing potion and second mixing part, respectively, and ε DE and ε WE are the strains at the DE and WE, respectively.

Measured strains are substituted into these simultaneous equations, and solving the equations determines the mixing force independently imposed on the first mixing part and the second mixing part.[5)]

2.2 Results of mixing force measurement

Examples of measured mixing force are described. **Fig. 8** shows the fluctuations of the mixing force measured at the first mixing part and second mixing part. **Fig. 9** shows the direction and magnitude of the mixing force at the moment when it reaches the maximum in the mixing part.

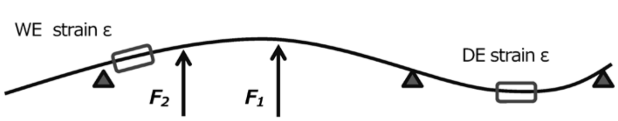

Fig. 7 Relationship between mixing force and strain

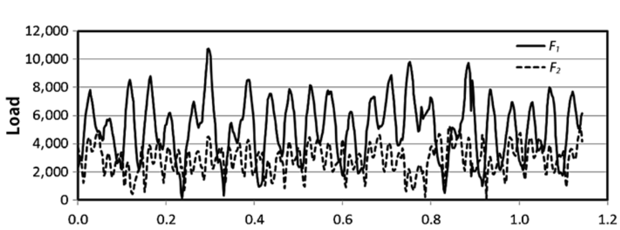

Fig. 8 Time history of mixing force

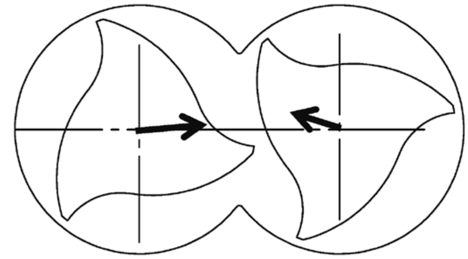

Fig. 9 Example of mixing force direction measurement

These evaluation results provide the basis for rotor design taking into account the load acting on the rotor during operation and without any risk of breakage, etc.

Conclusions

In the development of a new continuous mixer, it is essential to develop a rotor shape for improved mixing performance and an accurate mixing force measurement technology that supports it. These are regarded as the basis for the development of Kobe Steel's large mixers. The material development of HDPE is still being carried out by material manufacturers. Kobe Steel's continuous mixers must constantly improve their mixing performance so as to catch up with these developments.

The technologies introduced in this paper provide the foundation of future rotor development. The technologies can be combined with the flow analysis technology being developed by Kobe Steel's corporate research laboratories, to respond in a timely manner to market needs. Kobe Steel will continue to strengthen its technology development framework and further improve competitiveness.

References

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