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PAT

Luminance and brightness field distribution of light guiding plate for backlight panel (BLP) by micro molding

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This research investigates the luminance and the brightness field distribution of the microstructure of a light guiding plate (LGP) by micro injection molding (MIM) and micro injection-compression molding (MICM). The process of manufacturing a LGP includes photo-etching, MIM, MICM, and optical field measurement. The results show that the luminance of microstructure of LGPs produced using MICM is better than those made using MIM. The results also indicate that the most important processing parameter is the mold temperature for the luminance distribution of the LGP whether made by MIM or MICM. The maximum luminance of the LGP is 80 Nit (cd/m^2) on micro molding. The brightness field distribution of the LGP made using MICM is more uniform than those made using MIM for the same processing parameters. MICM is a more suitable process than MIM for the fabrication of a LGP on a backlight panel (BLP).

KEYWORDS: luminance; brightness field; light guiding plate; photo-etching; micro injection molding; micro injection-compression molding

INTRODUCTION

Backlight panel (BLP) is comprised of a light guiding plate (LGP), reflective sheets, diffusive sheets, prism sheets, and a cold cathode fluorescent lamp (CCFL). LGP is the major part of a BLP. Its function is to transfer the light of the CCFL to the face of the liquid crystal. The LGP must guide the light uniformly. So the scale quality and optical property of the LGP are very important.

Micro injection molding (MIM) is a new and rapidly evolving technology, which allows the production of components at a scale and an intricate level of detail not possible using conventional injection molding techniques. Bűrkle and Wohlrab[1] discussed the precision technique for injection-mold parts without residual stress. The results showed that the optical element (such as lens or prism) has low birefringence, low residual stress, and low clamping force by using injection-compression molding. Yoshii *et al.*[2] discussed the replication of micro grooves of optical disks manufactured by injection molding, investigating the effects of melt temperature, mold temperature, injection rate, holding pressure, and holding time. The results showed that high mold temperature induced good replication of a micro groove. The replication improved when the mold temperature nearly reached the glass transition temperature of the material. Heckele and Schomburg[3] reviewed the micro molding of thermoplastic polymers. The results showed the comparison between different polymers (such as COC, PMMA, etc.) and different molding methods (hot embossing, injection molding, reaction injection molding, compression molding, and thermoforming) for application on micro components. Pan and Su[4] pointed out a new process to fabricate a gapless triangular micro-lens array (GTMA). The process included UV lithography, photo resist reflow process, Ni–Co electroplating, and hot embossing. The results showed that the optical film with GTMA pattern increased 15.1% of luminance for the backlight module. Chien and Chen[5] fabricated an integrated LGP using microelectrical mechanical systems (MEMS) and a hot embossing technique. The results showed that the maximum illumination was 462.1 lux and the minimum illumination was 370.4 lux. The uniformity of illumination of the LGP was 86.9%. Kim[6] developed a diffusing plate (PMMA) modified with glass fibers in the backlight unit of a liquid crystal display. The results indicated that the warpage of the diffusing plate was significantly reduced relative to that of a conventional diffusing plate. Fujisawa *et al.*[7] proposed a

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novel edge-light backlight unit using an optically patterned film (OPF) for LCD, which is composed of a light guide plate bonded to the top of fine lens formed on the OPF. The results showed that the extraction efficiency of OPF backlight unit was greater than that of a conventional backlight unit. Kim *et al.*[8] developed an internal patterning in the light guide plate by applying laser engraving. The results indicated that the LGP manufactured by the internal patterning offers better efficiency than is provided by conventional bottom surface patterning.

The purpose of this paper is to discuss the luminance and brightness field properties of the microstructure of the LGP for different processing parameters by MIM and micro injection-compression molding (MICM).

MOLD INSERT FABRICATION AND EXPERIMENTS

The two-plated mold was employed in the micro molding studies (MIM and MICM) in this study.[9] The length and width of the mold insert is $40 \times 32.5\,mm^2$; the thick end is 3.4 mm, and the thin end is 1.0 mm. The microstructure is semi-spherical in shape. Its height is 57.6 μm and its diameter is 100–300 μm from the thick end to the thin end by linearity expansion. The material of the mold insert is SUS 430 stainless steel. The insert is fabricated by photo-etching (process chart for photo-etching is shown in Fig. 1). Firstly, the steel is cleaned and degreased by using a degreasing liquid. Cr material is used to design and fabricate the photo mask from the original pattern design. Then, the AZ-440 photo resist is coated on the surface of mold steel with a spin coater. The UV light source exposes the photo resist by photo mask. After the exposure process, the photo resist is developed using the development liquid. Then, the $FeCl_3$ liquid is used to etch into the mold insert where there are no photo resists for pattern shape. Finally, the residual photo resist is removed and the mold insert is cleaned. An optical microscope (Vertx 220, UK) was used to measure the microstructures of the mold insert. The mold insert was fabricated very well.[9]

Micro molding studies were performed on an Arburg 220S 256-60 injection-molding machine (Regloplus). This machine has a maximum clamping force of 25 tons and a maximum shot size of $20\,cm^3$. Oil is used to transfer heat by the mold temperature control. The temperature range of this machine is 20–300°C and its precision is ±1°C. The LGP is a transparent plate. Injection-grate PMMA Delpet 80NH (Asahi Kasei, Japan) was used in this research.[9]

To study the effects of process parameters on luminance and brightness properties of LGPs, five process parameters, including the mold temperature, melt temperature, packing pressure, packing time, and cooling time, were chosen in MIM. Five process parameters, including the mold temperature, melt temperature, compression speed, compression distance, and cooling time, were chosen in MICM. In this study, a single-parameter method was used to discuss the luminance and brightness properties for different process parameters. The results of the single-parameter method are shown in Tables 1 and 2 for MIM and MICM respectively.

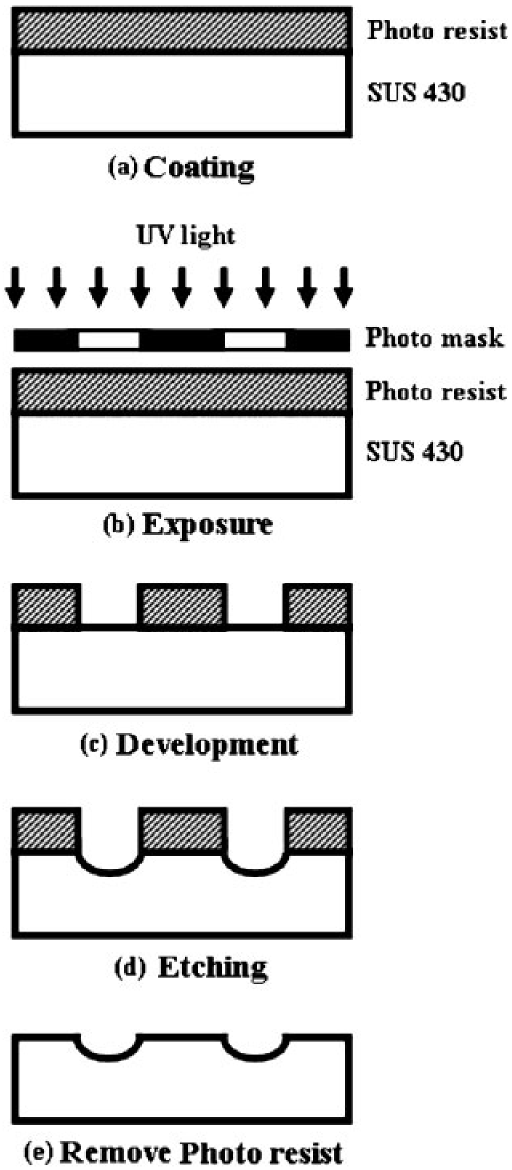

Figure 1. Process chart for photo-etching of mold insert.

We used a luminance meter (Konica Minolta LS-110) to measure the luminance distribution of microstructure of LGP for optical properties. There are 16 measurement points for the luminance distribution of microstructure of LGP (Fig. 2(a)). A texture developed by the authors to fix the BLP (LGP, reflective sheet, diffusive sheet, prism sheet, and CCFL) on the measurement platform (*x*–*y* table) was used in this research. The CCD color camera was located on the *z*-axis for the measurement platform to capture the brightness field of the LGP. The measurement system of the brightness field is shown in Fig. 2(b).

RESULTS AND DISCUSSION

This paper investigates the luminance and brightness distribution for the optical properties of the LGP by micro molding.

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Table 1. Single-parameter method for micro injection molding

Condition	Mold temperature (°C)	Melt temperature (°C)	Packing pressure (%)	Packing time (sec)	Cooling time (sec)
1	40	230	50	1	10
2	50	240	60	3	15
3	60	250	70	6	20
4	70	260	80	9	25

Table 2. Single-parameter method for micro injection-compression molding

Condition	Mold temperature (°C)	Melt temperature (°C)	Compression speed (mm/sec)	Compression distance (μm)	Cooling time (sec)
1	40	230	40	200	10
2	50	240	50	400	15
3	60	250	60	600	20
4	70	260	70	800	25

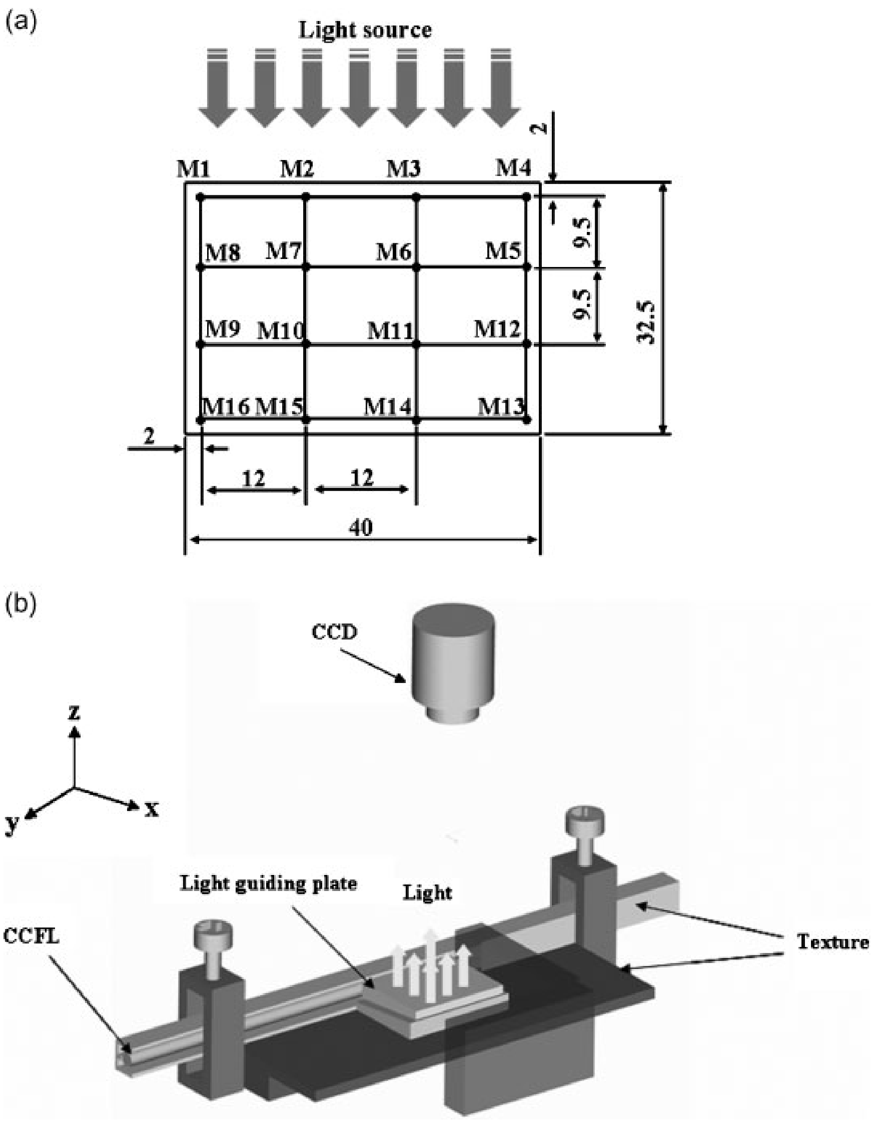

Figure 2. Luminance and brightness by measurement. (a) Luminance distribution for 16 measurement points. (b) The measurement system of brightness field.

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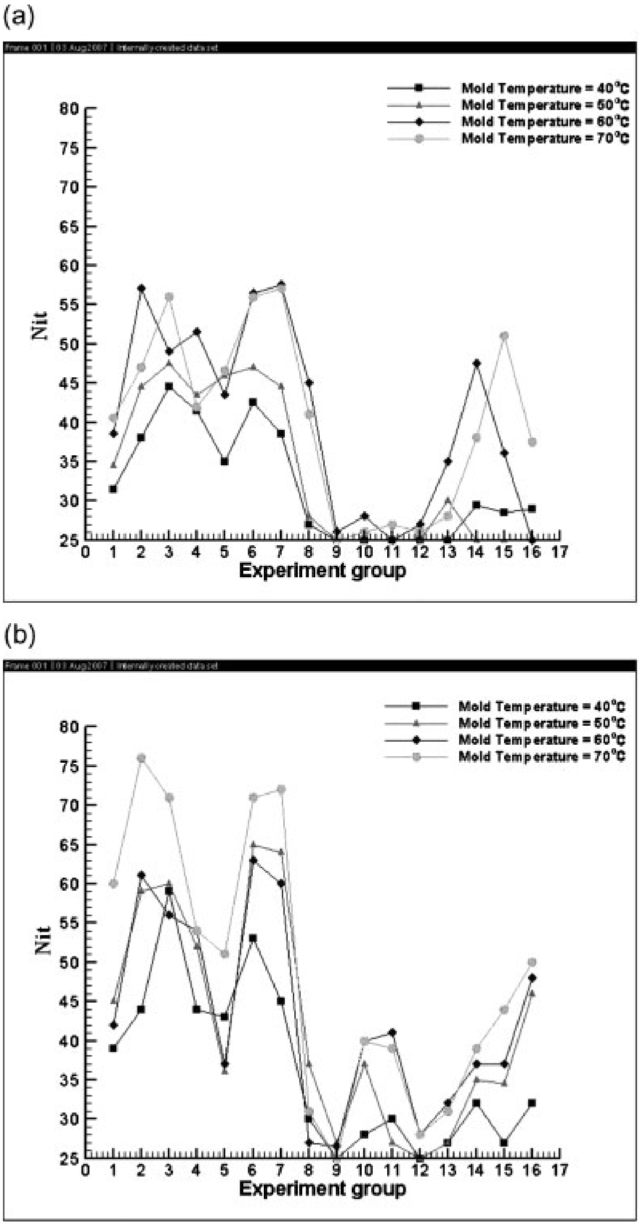

Figure 3. Luminance distribution for different mold temperatures. (a) MIM (melt temp. = 240°C, packing time = 3 sec, packing pressure = 150 MPa, cooling time = 15 sec). (b) MICM (melt temp. = 240°C, compression speed = 50 mm/sec, compression distance = 400 μm, cooling time = 15 sec).

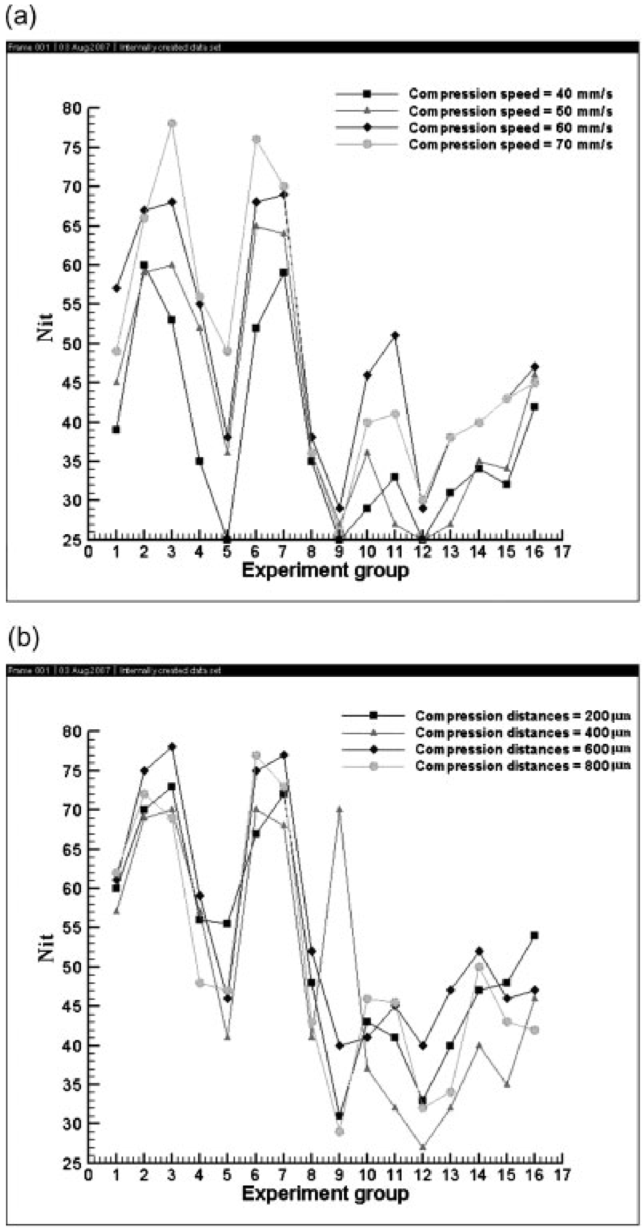

Figure 4. Luminance distribution by MICM. (a) Mold temp. = 50°C, melt temp. = 240°C, compression distance = 400 μm, cooling time = 15 sec. (b) Mold temp. = 50°C, melt temp. = 240°C, compression speed = 50 mm/sec, cooling time = 15 sec.

Figure 3 shows the luminance distribution of microstructure of LGP for different mold temperatures by different micro moldings. The luminance of points 1, 2, 3, 4 has a greater value than that of the other points. The reason is that these points are close to the light source. The luminance of points 2 and 3 has the biggest value. The reason is that with the exception of the present result, these points are located on the central region of the LGP and do not obscure the strength of light source by the side wall. The luminance distribution for different columns is decreasing first and then increasing in the final column. The luminance of points 13, 14, 15, 16 is larger than that of points 9, 10, 11, and 12. The radius of the microstructures of these points has the maximum value. So the reflection of these points can improve more than that of the smaller microstructures. The luminance at the side region, of points (8, 9, 5, 12) is lower in value than that at central points. The reason is that the light arrives in the side region and reflects on the central region. So the luminance of the side region of the LGP is reduced. The luminance of points 9, 10, 11, 12 has the minimum value. The reason is that these points are far away from the light source and their radius is not so large as to reflect enough light. The luminance of points 6 and 7 is nearly the same as points 2 and 3, because they are close to the light source and their size (diameter) is larger than that of points 2 and 3. The results also indicate that the luminance distribution of the

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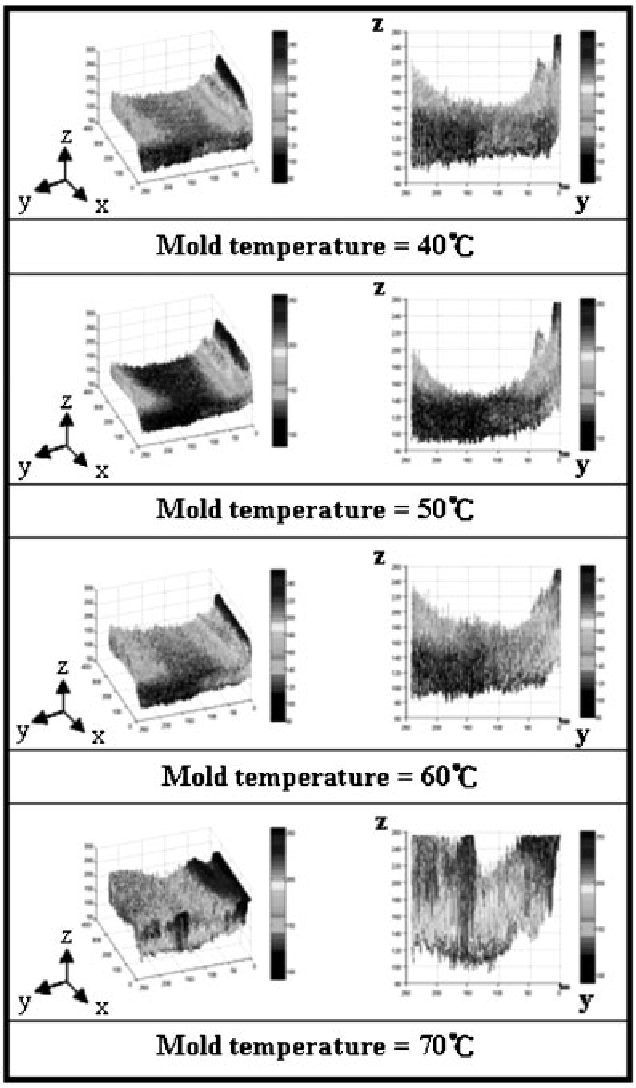

Figure 5. Brightness field distribution for different mold temperatures (MIM, melt temp. = 240°C, packing time = 3 sec, packing pressure = 150 MPa, cooling time = 15 sec).

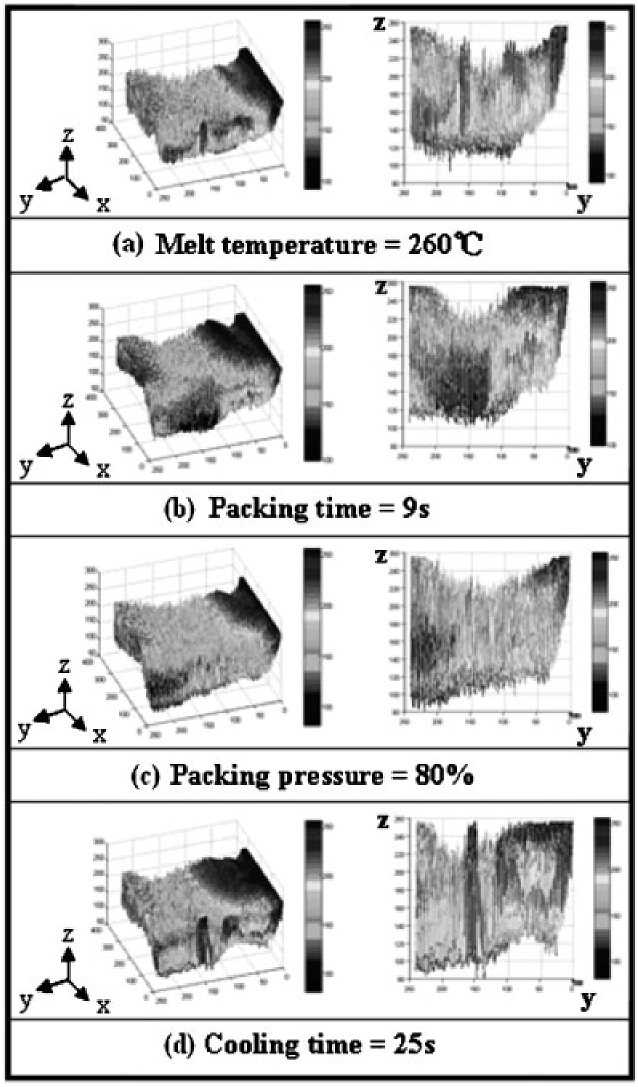

Figure 6. Brightness field distribution for MIM. (a) Mold temp. = 50°C, packing time = 3 sec, packing pressure = 60%, cooling time = 15 sec. (b) Mold temp. = 50°C, melt temp. = 240°C, packing pressure = 60%, cooling time = 15 sec. sec. (c) Mold temp. = 50°C, melt temp. = 240°C, packing time = 3 sec, cooling time = 15 sec. (d) Mold temp. = 50°C, melt temp. = 240°C, packing time = 3 sec, packing pressure = 60%.

microstructure of the LGP increases as the mold temperature increases. The reason is that the mold temperature is lower, so the hot melted plastic touches the mold wall to form solid layer quickly. This situation causes transparency but not uniformity in the final product. Luminance distribution of the microstructure of the LGP by MICM is larger than that by MIM. Luminance distribution of the microstructure of the LGP for different melt temperatures and cooling times is very similar to the results presented by micro molding. Luminance distribution of the microstructure of the LGP also increases as the melt temperature increases. The reason is that higher melt temperature of the melting plastic can cause the cooling situation to be uniform. The product will have better transparency, and the luminance distribution also gets a better result. Luminance distribution of the microstructure of the LGP decreases as the cooling time increases. If the cooling time is longer, the cooling situation of LGP shows a different layer from surface to core. The transparency of the product is not good. Luminance distribution of the microstructure of the LGP increases as packing time and packing pressure increases by MIM. Higher packing time and packing pressure induce the LGP to be more flat. This situation causes the luminance distribution to be better. Figure 4 shows the luminance distribution for different compression speeds and compression distances by MICM. The luminance distributions of 16 points of microstructure of LGP show the same situation as the present results. The results indicate that the luminance distribution of the microstructure of the LGP increases as the compression speed increases. Higher compression speed causes a flatter LGP. The luminance distribution then improves. Luminance distribution of the microstructure of the LGP increases as the compression distance increases. But luminance gets the maximum value when compression distance is 600 μm and

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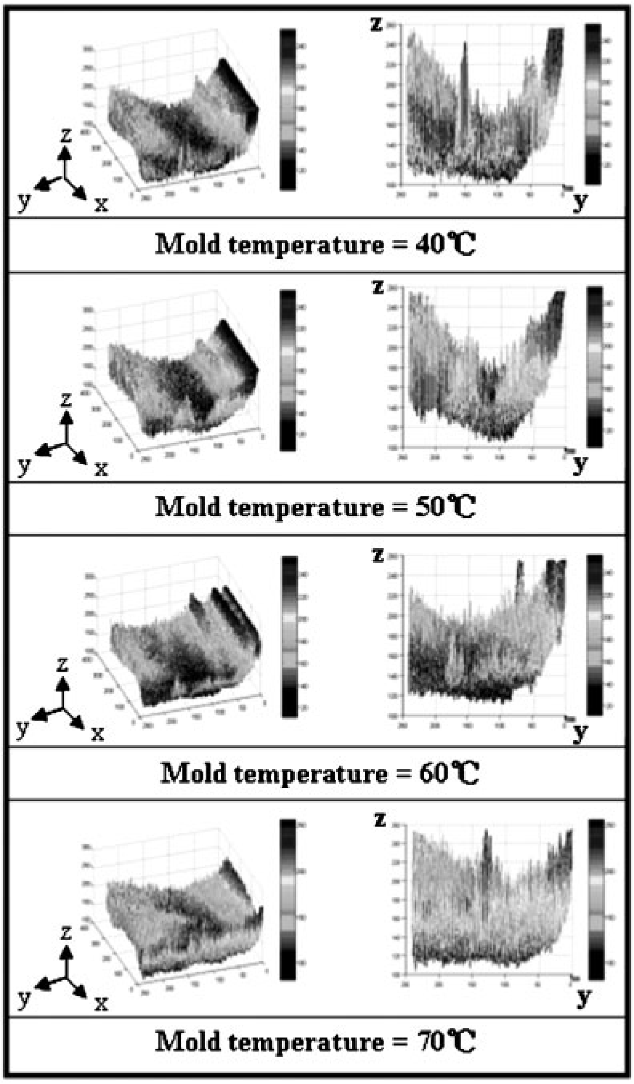

Figure 7. Brightness field distribution for different mold temperatures (MICM, melt temp. = 240°C, compression speed = 50 mm/sec, compression distance = 400 μm, cooling time = 15 sec).

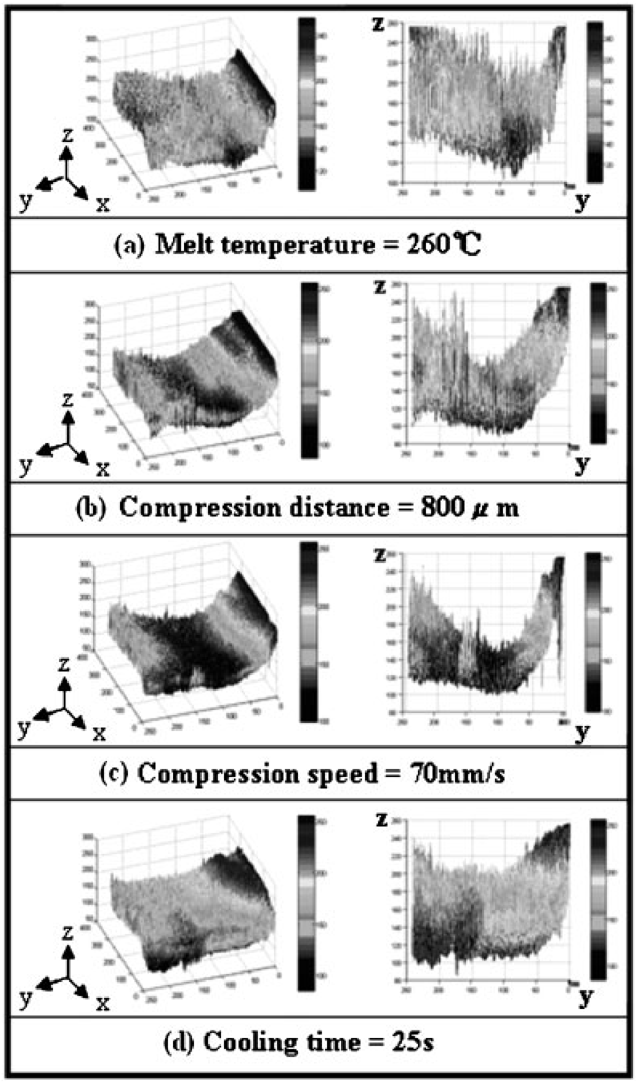

Figure 8. Brightness field distribution for MICM. (a) Mold temp. = 50°C, compression speed = 50 mm/sec, compression distance = 400 μm, cooling time = 15 sec. (b) Mold temp. = 50°C, melt temp. = 240°C, compression speed = 50 mm/sec, cooling time = 15 sec. (c) Mold temp. = 50°C, melt temp. = 240°C, compression distance = 400 μm, cooling time = 15 sec. sec. (d) Mold temp. = 50°C, melt temp. = 240°C, compression distance = 400 μm, compression speed = 50 mm/sec.

then its value decreases. When compression distance is too long, the hot melted plastic forms a solid layer on the mold wall. The final product shows different transparency degrees, and the luminance distribution worsens. Luminance distribution of the microstructure of the LGP also increases as the melt temperature increases. The reason is that the higher melt temperature of the melting plastic can cause the cooling situation to be uniform. The product will have better transparency, and luminance distribution also gets a better result. Luminance distribution of microstructure of LGP becomes more uniform for various mold temperatures than the other processing parameters on MIM. The results indicate that the luminance distribution also becomes more uniform for various mold temperatures as compared to the other processing parameters on MICM. So mold temperature is the most important processing parameter for the luminance distribution of the LGP on micro molding. The luminance value of microstructure of LGP made by MICM is higher than that made by MIM for the same mold temperature, melt temperature, and cooling time. The results show that the MICM is a better process for luminance distribution of the LGP.

Figure 5 shows the brightness field distribution of microstructure of LGP for different mold temperatures by MIM. The light source (CCFL) is located on the plane ($y = 0$). Brightness field distribution increases as the mold temperature increases. The results show that the brightness field indicates a stronger value on the near end and the faraway light source. This situation is very similar to the results for luminance distribution. The results also demonstrate that brightness field distribution is very uniform with a higher mold temperature. Another reason is the result of luminance distribution. Figure 6 shows the brightness field for MIM on different processing parameters. Brightness field distribution

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increases as melt temperature, packing time, packing pressure, and cooling time increase. The result indicates that brightness field becomes more uniform with a higher melt temperature, packing time, packing pressure, and cooling time. It also shows that mold temperature is the most important processing factor for brightness field distribution of the LGP by MIM in Figs 5 and 6. Brightness field distribution of microstructure of LGP for different mold temperatures by MICM is shown in Fig. 7. The results show that the brightness field distribution increases as the mold temperature increases. Brightness field distribution is more uniform as the mold temperature becomes higher. Figure 8 shows the brightness field distribution for MICM on different processing parameters. The results demonstrate that brightness field distribution increases as the melt temperature, compression speed, and cooling time increase. Brightness field distribution increases as the compression distance increases. But its value decreases if the compression distance is equal to 800 μm. The results also indicate that: (i) brightness field distribution is more uniform as the melt temperature, compression distance, compression speed, and cooling time increase; (ii) the brightness field by MICM is larger than that by MIM for the same mold temperature, and (iii) the brightness field by MIM is smaller than that by MICM for the same melt temperature and cooling time. Brightness field distribution of the LGP by MICM is more uniform than by MIM for the same mold temperature, melt temperature, and cooling time. To sum up, mold temperature is also the most important factor for the brightness property of the LGP by micro molding. MICM is a more suitable process than MIM for the brightness property of the LGP.

CONCLUSION

The results of this paper show that mold temperature is the most significant factor of the processing parameters for optical properties in MIM; the second is melt temperature, and the third is packing pressure. Mold temperature is also the most significant factor of the processing parameters for optical properties in MICM; the second is melt temperature, and the third is compression speed. To sum up, mold temperature is the most important processing parameter for the optical property of the LGP by micro molding. The results also show that the process of MICM is better than MIM for optical properties of microstructure of the LGP. The optical property of the LGP for the points close to the light source has the best situation, then the points that are further away from the light source.

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