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Effects of Mold Cavity Temperature on Surface Quality and Mechanical Properties of Nanoparticle-Filled Polymer in Rapid Heat Cycle Molding

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ABSTRACT: Acrylonitrile-butadiene-styrene (ABS)/poly methyl methacrylate (PMMA) and ABS/PMMA/nano-$CaCO_3$ composites were prepared in a corotating twin screw extruder. Single-gate and double-gate samples were molded based on a rapid heat cycle molding (RHCM) system. Effects of mold cavity temperature on surface quality and mechanical properties of single-gate and double-gate samples in RHCM process were conducted. The results showed that surface quality of plastic parts can be improved significantly by increasing mold cavity temperature. Nano-$CaCO_3$ particles on the surface of plastic parts can be eliminated by using high mold cavity temperature. The roughness and gloss of two kinds of plastic parts (ABS/PMMA and ABS/PMMA/nano-$CaCO_3$) stabilized at the same level when the mold cavity temperature is above glass transition temperature of resin material. Weld line can be eliminated in RHCM process during high mold cavity temperature. The tensile strength of both ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ exhibited decreasing trend with the increase of mold cavity temperature. Reduction of internal stress gave rise to the increase of Izod impact strength of ABS/PMMA for both sing-gate and double-gate samples. However, influence regularity of mold cavity temperature on Izod impact strength of ABS/PMMA/nano-$CaCO_3$ is depended on the number of gates. For all the samples in this study, too high of mold cavity temperature (higher than 125°C) deprave Izod impact strength of plastic parts. Both ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ are not susceptible to weld line. When the mold surface temperature is approximately equal to glass transition temperature of resin material, all the samples are found to give the best combination of properties. © 2014 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2015**, *132*, 41420.

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INTRODUCTION

Rapid heat cycle molding (RHCM) is a recently developed injection molding technology to enhance surface esthetic of plastic parts. In RHCM process, the mold cavity is rapid heated up to the glass transition temperature of resin before filling stage. During filling and packing stage, the mold should be always kept at high temperature in order to improve the flow ability of the polymer melt. At the end of packing stage, the mold cavity is cooled down quickly so as to freeze the polymer melt for demolding. And then the mold will be heated again for the next injection cycle. Since the mold cavity temperature is kept at a high level during filling and packing stage, the flow ability of melt is significantly improved and the premature freezing of polymer melt during filling stage is avoided. Therefore, plastic parts with good surfaces can be obtained especially for inorganic particle filled polymer. Products made in RHCM process will have a nice appearance without painting. So this process is environment friendly and low cost in some areas.

Processing parameters, mold technology and material properties are three critical factors for RHCM process. Materials with high gloss, good mechanical properties, and low cost are needed for this process. Acrylonitrile-butadiene-styrene (ABS)/poly methyl methacrylate (PMMA) is an attractive blend owing to its good mechanical, optical properties, and relatively low cost. Therefore, ABS/PMMA is quite suitable for RHCM process. However, little research has been carried out on ABS/PMMA blends.[1–5] To enhance properties and/or lower costs of ABS/PMMA, incorporation of inorganic particles is a promising approach. Nano-calcium carbonate (nano-$CaCO_3$) is one of the most important inorganic fillers for resins modification. Our team has done some work about ABS/PMMA/nano-$CaCO_3$ blends.[6,7] It was revealed that collaborative use of aluminum–titanium compound coupling agent and stearic acid is best for surface modification of nano-$CaCO_3$ particles in ABS/PMMA/nano-$CaCO_3$ system. The optimal formula of ABS/PMMA/nano-$CaCO_3$ blend has been acquired.

In the past, studies on RHCM process are almost concentrated on the heating and cooling methods of mold.[8–19] However there is very limited research about the influence of processing parameters on surface and/or mechanical properties of the molded parts. Xie and Ziegmann[20] investigated the influence of processing parameters on micro injection molded weld line mechanical properties of polypropylene (PP). They used high power electrical heating pipes to realize the rapid heating. And cold water channels undertake the responsibility of rapid cooling. It was found that the influencing significance order of processing parameters from strong to week are mold temperature, melt temperature, injection speed, ejection temperature, packing pressure, and injection pressure. The V notch size in the specimens' middle part is larger and deeper than that in the edge. And the surface height in the middle surface is lower than that in the edge. Wang and Zhao[21] researched the reduction of sink mark and warpage of the molded part in RHCM process. And the external gas assisted packing was also proposed to reduce the sink mark in RHCM process. The results showed that the warpage of plastic parts was reduced effectively. Liu[22] investigated the affecting of mold temperature on shrinkage of plastic part in RHCM process. Results revealed that the shrinkage of RHCM part is reduced obviously compared with a conventional one. In addition to mold temperature, both packing pressure and packing time also had important influences on the shrinkage of plastic part. Wang and Zhao[23] found RHCM process can greatly increase the surface gloss of the part, especially for the fiber-reinforced plastics(polypropylene + 20% glass fiber). Li[24] studied the influence of mold temperature on tensile strength and fiber orientation of plastic parts in dynamic mold temperature injection technology. The relationship between tensile strength and dynamic mold temperature was demonstrated. Experiment results revealed that the mold temperature had a great effect on the tensile strength of fiber reinforced ABS.

The above studies showed that mold temperature had a significant influence on various properties of molded thermoplastic parts. The previous researches showed that some surface defects (such as sink mark and warpage) can be solved by using RHCM process. And the mechanical properties were also influenced by mold cavity temperature. However, thermoplastics and fiber reinforced thermoplastics were often chosen to research the influence of mold surface temperature on surface or strength of RHCM parts. And the research work about surface quality of plastic parts in RHCM process was only investigated simply. Inorganic particles filled thermoplastic was seldom studied in RHCM process.

In this article, we combined the polymer blending modification and RHCM process. Since surface quality and mechanical properties are two critical factors which affect the value of the product. Polymer filled with inorganic particles was chosen to investigate the influence of mold cavity temperature on these two factors of plastic parts in RHCM processing. Aluminum–titanium compound coupling agent and stearic acid were used for the surface modification of nano-$CaCO_3$ particles. ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ composites were prepared in a corotating twin screw extruder. Single-gate and double-gate samples were molded based on a RHCM system with electric heating. Effects of mold cavity temperature on surface quality and mechanical properties of single-gate and double-gate samples in RHCM process were conducted.

EXPERIMENTAL

Materials

ABS resin (0215A) and PMMA resin (CM207) were purchased from Jilin Petrochemical and Taiwan chimei, respectively. Nano-$CaCO_3$ without any treatment was obtained from Hangzhou Wanjing New Material. The mean diameter of nano-$CaCO_3$ particles is ~100 nm. The aluminum–titanium compound coupling agent (HW-133) was provided by Hangzhou Feidian chemical. The stearic acid was provided by Tianjin Fuchen chemical reagent factory.

Sample Preparation

In order to make the mixture more uniform, aluminum-titanium compound coupling agent was cut into small pieces and divided into three parts. One part of coupling agent and nano-$CaCO_3$ particles were put into a type 6202 high-speed grinder for stirring. The other two parts of coupling agent were put into the grinder successively during the stirring. The total mass ratio of aluminum–titanium compound coupling agent is 1 wt %. After mixing for 25 min, stearic acid (mass ratio: 0.5 wt %) was added into the mixture. Materials in the grinder continued mixing for another 5 min.

All of the materials were pre-dried in an air circulating oven at 80°C for 12 h to remove all the moisture. ABS, PMMA, and nano-$CaCO_3$ were put into a corotating twin screw extruder with a screw diameter of 21 mm and length to diameter ratio of 36 for blending. Temperature profile of 205–225–235–220–180°C was set from the hopper to the die. The feed rate was kept at 3.6 kg/h and the screw speed was set at 120 rpm. The extruded pellets were put into the extruder for the second blending in order to improve the uniformity of the blends. ABS/PMMA (mass ratio: 80/20) and ABS/PMMA/nano-$CaCO_3$ (mass ratio: 80/20/10) pellets were obtained. Then the pellets were dried once again in an air circulating oven at 80°C for 12 h. The test samples as per ASTM standard specifications[25,26] were molded on a XL-680 68 tons injection molding machine. The experimental samples were shown in Figure 1. Six samples for tensile test, impact test, and heat deflection temperature test were molded in once time. Weld lines were formed for samples with double gates. Heat deflection temperature was not measured in this study, so four kinds of samples were used here.

An electric heating RHCM system was developed in our laboratory to produce single-gate samples and double-gate samples. Two heating rods with the power of 15 W/cm^2 were used for each sample in order to heat the mold quickly. Melt temperature, injection time, packing pressure, and packing time were kept constant. Different mold cavity temperature was acquired

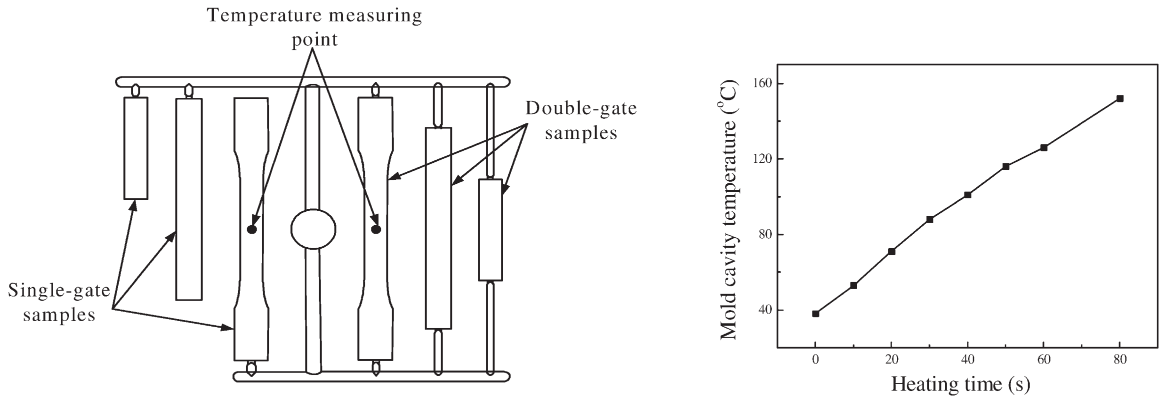

Figure 1. Experimental samples and the relationship between heating time and mold cavity temperature.

by changing heating time before filling. And the heating time arranged from 0 s to 80 s. After the injection process became stable, mold cavity temperature was measured by using thermocouples for five times and then the average temperature of mold cavity was obtained. The influence of melt on the mold cavity temperature was very little and can be ignored. The relationship between heating time and mold cavity temperature was shown in Figure 1.

Characterization

Mechanical properties such as tensile yield strength and Izod impact strength were measured. Tensile tests were carried out on a CMT 4204 20KN Electrical Testing Machine (maximum load: 20 KN) at room temperature according to ASTM D638.[25] The crosshead speed was kept at 5 mm/min. The dimensions of all the specimens made for Izod impact strength test were 63.5 mm × 12.7 mm × 6.35 mm with a V-shape notch according to ASTM D256.[26] And the notches were machined after molding. The tests were carried out on a XC-5.5D impact tester at room temperature.

A type of Wyko NT9300 white light interferometer, produced by Veeco Instruments, was used to characterize the morphology of the part surface. And a JFL-BZ60° gloss meter, produced by Tianjin jinfulun, was utilized to measure the gloss of the part surface. The surfaces of injection specimens were observed by a JEOL 6610LV SEM in order to evaluate the dispersion state of nano-$CaCO_3$ particles on the surface of ABS/PMMA/nano-$CaCO_3$ parts. Polymer specimens were coated with gold in an automatic sputter coater (E-1010 ion sputter) before the SEM observations.

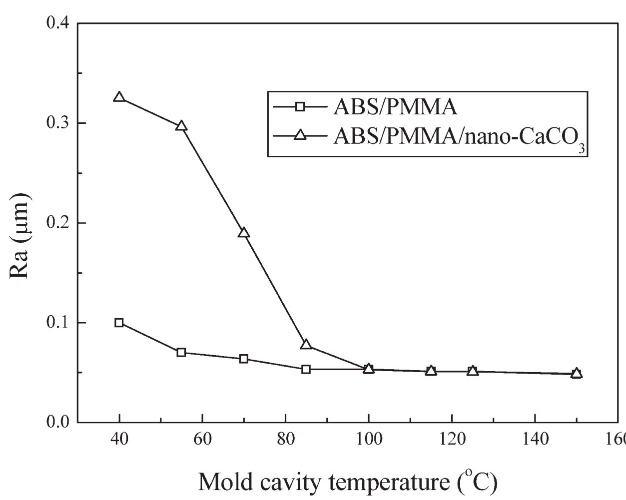

Figure 2. Effect of mold cavity temperature on the roughness of sample surface.

RESULTS AND DISCUSSION

Surface Quality

Roughness and Gloss. The roughness of various samples was measured by using white light interferometer. The roughness is quantified by Ra which is an integral of the absolute value of the roughness profile. The effect of mold cavity temperature on the roughness of sample surfaces is shown in Figure 2. When mold cavity temperature is about 40°C the Ra of sample surface is quite high, especially for ABS/PMMA/nano-$CaCO_3$ parts. The Ra of both ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ samples are decreased with the increasing mold cavity temperature. Then the Ra of two kinds of plastic parts (ABS/PMMA and ABS/PMMA/nano-$CaCO_3$) stabilizes at the same level when the mold cavity temperature is about 100°C. This phenomenon indicates that high mold cavity temperature in RHCM can eliminate the adverse effects of inorganic fillers on the surface quality of plastic part. When the temperature of mold cavity is higher than 100°C, the influence of mold cavity temperature on Ra of plastic parts is very little and even can be ignored. Figures 3 and 4 are surface morphology of ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ samples, respectively. It can be found that the surface of ABS/PMMA/nano-$CaCO_3$ is much rougher than that of ABS/PMMA with low mold cavity temperature. This is attributed to nano-$CaCO_3$ particles on the surface of plastic parts. However, the surface quality is significantly improved when the mold cavity temperature is about 100°C.

The gloss of various samples was measured by using gloss meter. Figure 5 indicates that the effect of mold cavity temperature on the gloss of sample surface. Contrary to roughness, the gloss of both ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ parts is increased significantly with the increase of mold cavity temperature. Gloss of plastic surface is related to both roughness of surface and the nature of material itself.

ABS is based on three monomers: acrylonitrile, butadiene, and styrene. And continuous phase of ABS consists of copolymer

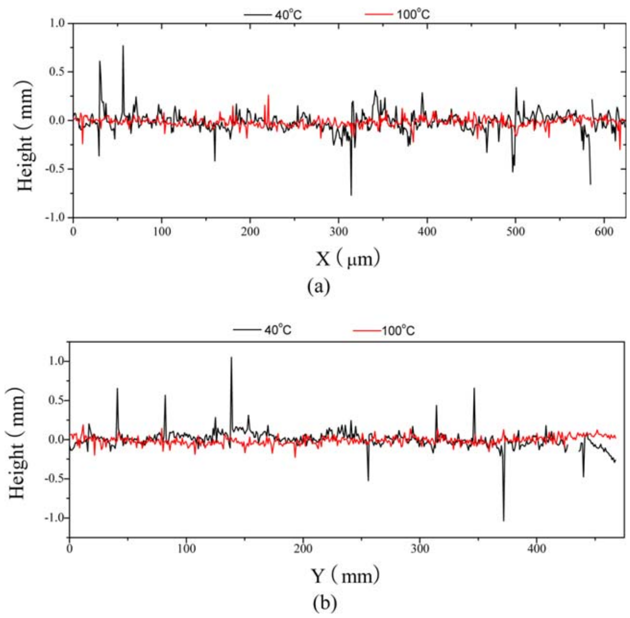

Figure 3. Surface morphology of ABS/PMMA specimens (a) X direction (flow direction) profile curve; (b) Y direction (vertical direction of flow) profile curve. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

(SAN) of styrene and acrylonitril. An elastomer based on butadiene (PB) forms the disperse phase which is distributed in the continuous phase. SAN exhibits good flow ability and gloss while PB often deteriorates flow ability and gloss of polymer material (ABS). However, PMMA is also a kind of polymer materials with high gloss. When the mold cavity temperature is low, the melt freezes quickly as soon as it contacts the cold mold wall. Thus, a premature frozen layer which leads to an ugly part surface is formed during filling stage. However, the flow ability of melt is significantly improved and the premature frozen layer is avoided when mold cavity temperature is higher than glass transition temperature of resin. The resin phase (SAN or PMMA) can flow freely in the mold and wrapped the rubber phase (PB) during filling stage. Therefore the resin can duplicate the mold surface much better and the Ra of plastic part surface will be decreased greatly. The higher the Ra is, the lower the gloss is. On the other hand, both SAN and PMMA form the skin of plastic parts, thus a good gloss finish can be got because of high gloss of SAN and PMMA.

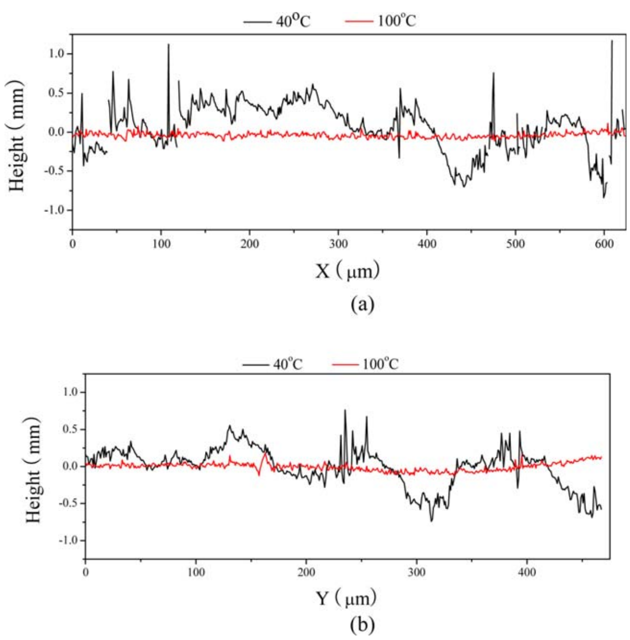

Figure 4. Surface morphology of ABS/PMMA/nano-$CaCO_3$ specimens (a) X direction (flow direction) profile curve; (b) Y direction (vertical direction of flow) profile curve. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

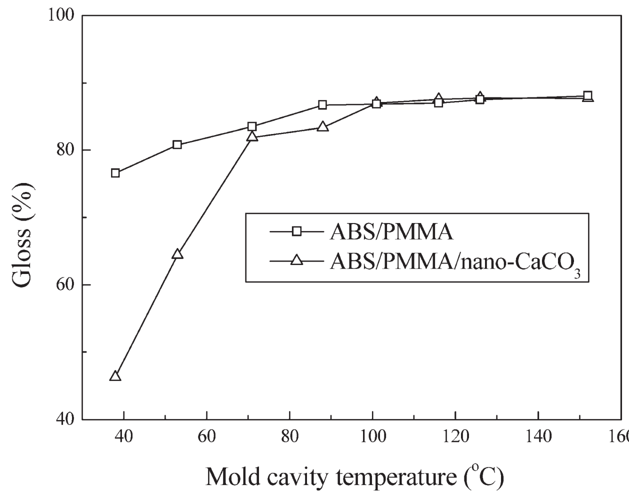

Figure 5. Effect of mold cavity temperature on the gloss of sample surface.

Furthermore, the influence of mold cavity temperature on the surface quality of ABS/PMMA/nano-$CaCO_3$ parts is much greater comparing with ABS/PMMA. When the mold cavity temperature is about 40°C, many $CaCO_3$ particles are exposed on the surface of parts as shown in Figure 6(a). However with the increase of mold cavity temperature, resin phase can flow freely in the mold and wrap $CaCO_3$ particles. And fewer and fewer $CaCO_3$ particles are exposed on the surface of parts from Figure 6(a,d). When the mold cavity temperature is above 100°C the resin phase can cover $CaCO_3$ particles thoroughly as shown in Figure 6(d). So the roughness and gloss of ABS/PMMA/nano-$CaCO_3$ parts are same to that of ABS/PMMA parts when the mold cavity temperature is above 100°C.

Weld Line. "Fountain flow" often appears in injection process. The flow velocity is decreased from center to wall of the mold while the shear rate is increased from center to wall of the mold. When the core melt reaches to the flow front, it will begin to flow toward the wall. Then laminar flow changes over to radial flow. Weld lines are created when two flow fronts meet together.[27] When the mold cavity temperature is low, flow melts will be frozen as soon as they reach to the mold wall. The premature solidification is bad for the welding of the two flow melts. And a "v" notch is formed as shown in Figure 7. The premature frozen can be eliminated with the increase of mold

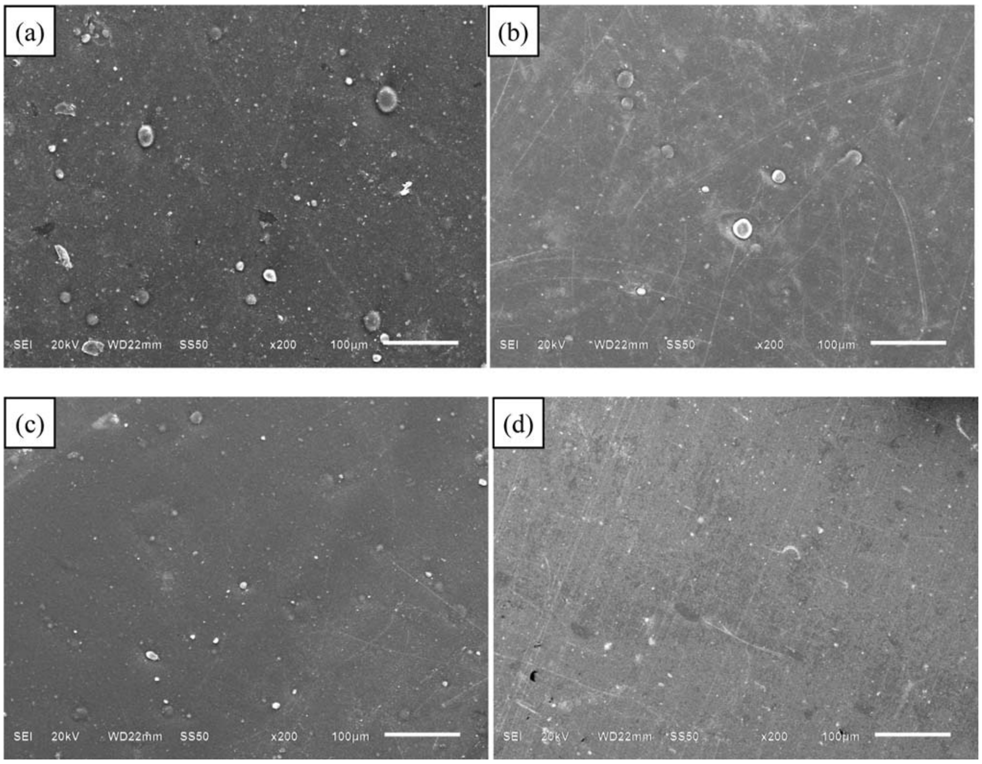

Figure 6. The surface micrographs of ABS/PMMA/$CaCO_3$ specimens at different mold cavity temperature (a) 40°C; (b) 70°C; (c) 100°C; (d) 125°C.

cavity temperature as we discussed before. Thus melts can be welded adequately and molecular inter diffusion is much easier. So the "v" notch becomes smaller and smaller with the increase of the mold cavity temperature. The photograph of surface morphology obtained by white light interferometer is illustrated in Figure 8. The weld line region is black because little light is received by white interferometer in weld line region. Thus the width of weld line can be acquired by measuring the width of black region in Figure 8. Figure 9 gives the relationship between mold cavity temperature and width of weld line. When the mold cavity temperature is lower than 110°C, the width of weld line decreased quickly with the increase of mold cavity temperature. And the width of weld line changes to 0 when the mold cavity temperature is higher than 110°C. Namely, when the mold cavity temperature is higher than 110°C the weld line is eliminated.

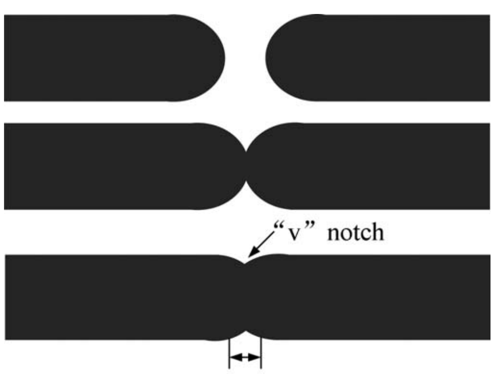

Figure 7. The schematic diagram of weld line formation.

Mechanical Properties

Single-Gate Sample. Figure 10 illustrates the effect of mold cavity temperature on tensile strength of single-gate samples. It shows that the tensile strengths of both ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ decrease with the increase of mold cavity temperature. This phenomenon is similar with PC/ABS studied by Lim.[28] When mold cavity temperature increases from 40°C to 150°C, the decrease in tensile strength for ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ is 6.2% and 4.7%, respectively.

As we discussed in the previous paragraph, when the mold cavity temperature is low, the melt laminar at the skin is frozen quickly, and a premature frozen layer whose velocity is zero was created. However the velocity of melt laminar at the core is the highest. Thus, the velocity gradient is very high from core to skin and it will increase the shear rate in the melt. High shear rate promotes the orientation of polymer chains. So anisotropy of samples is exhibited. Polymer chains are oriented along the flow direction and the direction of tensile force is also along the flow direction. Thus the tensile strength is high. However, with the increase of mold cavity temperature, the premature frozen layer is becoming thinner and thinner, and then eliminated finally. At this time, melt at the skin can freely flow in the injection process. So the velocity gradient from core to skin and the shear rate are both reduced. In addition, high mold temperature will increase the melt temperature and then reduce the viscosity of melt. The low viscosity will also reduce the shear rate of

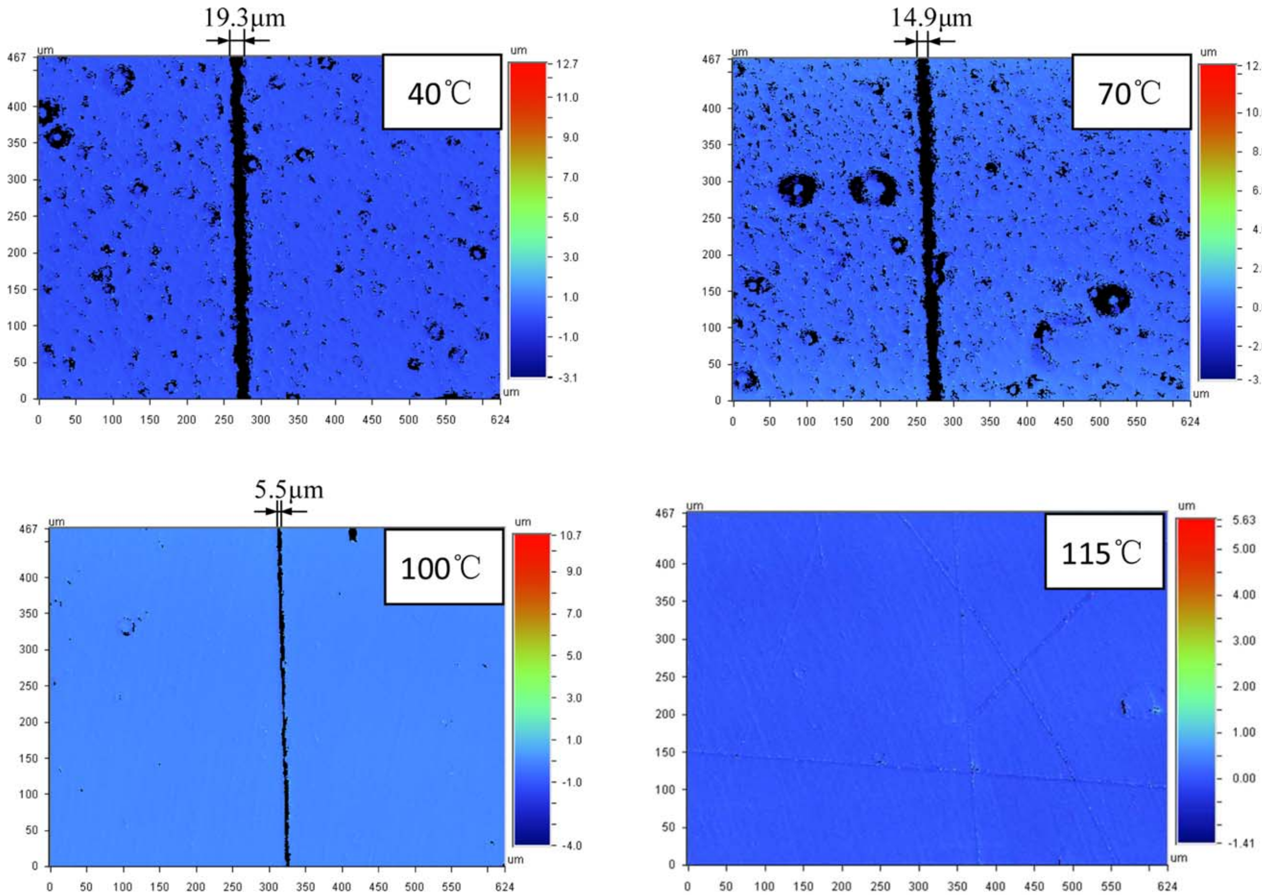

Figure 8. Surface morphology of weld line of ABS/PMMA/nano-$CaCO_3$ plastic. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

melt. Therefore, degree of polymer chains' orientation is reduced because of lower shear rate. On the other hand, high melt temperature-enhanced disorientation ability of polymer chains. And this will also reduce the degree of polymer chains' orientation. Thus tensile strength is decreased with the increase of mold cavity temperature.

Figure 11 illustrates the effect of mold cavity temperature on Izod impact strength of single-gate samples. It shows that Izod impact strength of ABS/PMMA gradually increases with the

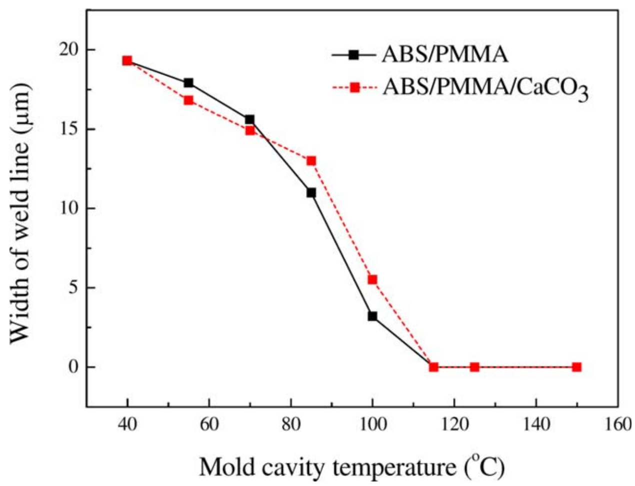

Figure 9. Effect of mold cavity temperature on width of weld line. [Color figure can be viewed in the online issue, which is available at wileyonline-library.com.]

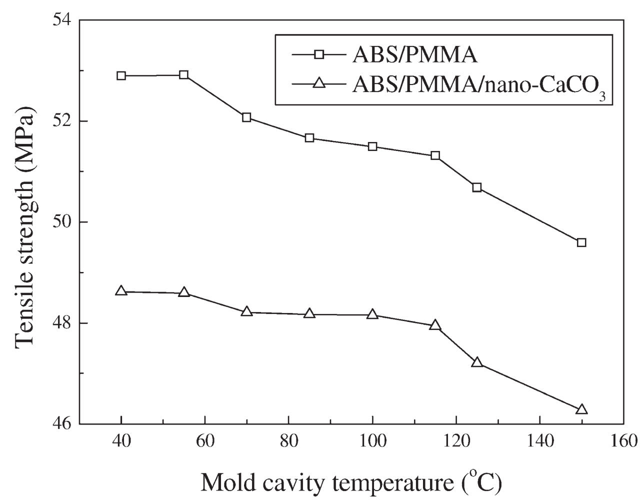

Figure 10. Effect of mold cavity temperature on tensile strength of single-gate samples.

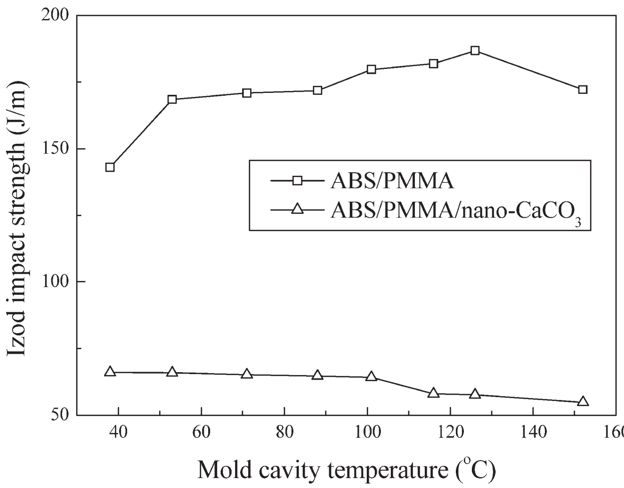

Figure 11. Effect of mold cavity temperature on Izod impact strength of single-gate samples.

increase of mold cavity temperature firstly. And then the Izod impact strength of ABS/PMMA becomes to decrease when the mold cavity temperature is higher than 125°C.

Izod impact strength is closely related to the internal stress of plastic part. The impact strength is related to the internal stress. Orientation stress and thermal stress are two kinds of internal stresses created in injection process. Orientation stress and thermal stress are attributed to the orientation of polymer chains and the temperature gradient, respectively. As we discussed in the previous paragraph, the orientation degree and, consequently, the orientation stress, are reduced with the increase of mold cavity temperature. When the mold cavity temperature is high enough, the premature frozen layer will be eliminated gradually. This illustrates that all of the melt (skin and core) will maintain high temperature during the filling stage. Temperature gradient from core to skin will also be reduced. Apparently, thermal stress created by temperature gradient is decreased to a low level. The reduction of orientation stress and thermal stress will give rise to the increase of Izod impact strength as shown in Figure 11. However, when the mold cavity temperature is too high (higher than 125°C), the shrinkage of samples is very serious and the cross sectional area is consequently reduced. Thus, Izod impact strength will decrease.

Comparing with ABS/PMMA, the variation of Izod impact strength for ABS/PMMA/nano-$CaCO_3$ with mold cavity temperature is opposite. Resin phase can flow freely in the mold and wrapped $CaCO_3$ particles during high mold cavity temperature. This will cause uneven distribution of $CaCO_3$ in the plastic parts. Most of $CaCO_3$ particles are aggregated in the core. The incorporation of nano-$CaCO_3$ particles will deprave the toughness of plastic parts.[6] The more the $CaCO_3$ particles are, the lower the Izod impact strength of plastic part is. Most of $CaCO_3$ particles in the core significantly decrease the toughness of plastic part. The inhomogeneity of plastic part causes reduction of Izod impact strength. On the contrary, the reduction of internal stress will increase the Izod impact strength. By the both effection, the Izod impact strength of ABS/PMMA/nano-$CaCO_3$ is decreased slightly with the increase of mold cavity temperature.

Double-Gate Sample. In this study two gates were used to form welded samples as shown in Figure 1. The morphology of weld line is closely related to the movement of polymer chains. Radial flow at the weld line causes polymer chains to oriented perpendicular to the flow direction. Two streams of melt from two gates cannot diffuse adequately during filling stage, so fewer entanglements are formed in the weld line. Therefore, the weld line becomes the weakest point of the plastic part. And welded samples are often broken at the weld line during tensile test.

Weld line factor is often used to present weld line properties.[29] It is defined as:

$$\text{WL-factor} = \text{strength with weld line}/\text{strength without weld line} \quad (1)$$

Table I shows WL-factors of ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ during different mold cavity temperature. It showed that WL-factors of both ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ are above 0.95. This phenomenon implies that weld line has little effect on strength of ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ samples.

With the increasing mold cavity temperature, "v" notch at weld line becomes smaller and smaller and then the strength of welded samples is increased. At the same time orientation degree decreased gradually, so tensile strength is reduced. Since ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ are not susceptible to weld line, the increase of weld line strength (caused by increasing mold cavity temperature) is not obvious. Thus, tensile strength of welded samples is also decreased with the increase of mold cavity temperature as shown in Figure 12.

Figure 13 illustrates the effect of mold cavity temperature on Izod impact strength of double-gate samples. For both ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ systems, the Izod impact strength of double-gate samples is much lower than

Table I. WL-Factors of ABS/PMMA and ABS/PMMA/Nano-$CaCO_3$ at Different Mold Cavity Temperature

	Mold cavity temperature (°C)							
WL-factor	40	55	70	85	100	115	125	150
ABS/PMMA	0.96	0.96	0.98	0.97	0.97	0.96	0.96	0.98
ABS/PMMA/nano-$CaCO_3$	0.98	0.98	0.97	0.97	0.97	0.97	0.96	0.96

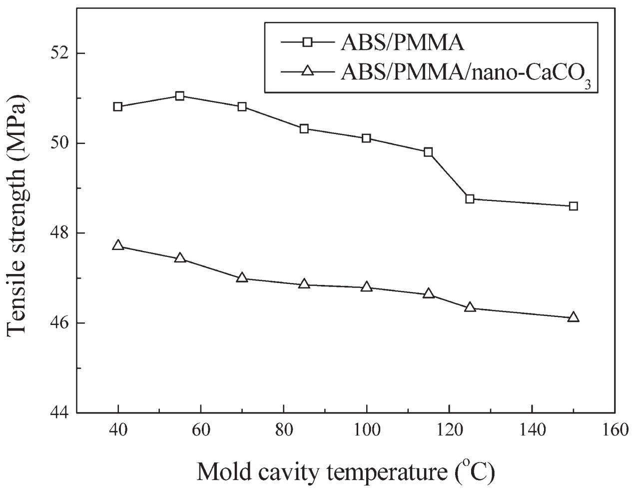

Figure 12. Effect of mold cavity temperature on tensile strength of double-gate samples.

that of single-gate samples. The presence of weld line decreases the impact strength of polymer blends to a great extent. This phenomenon was also found in PS system by Lu in 2004.[30]

For ABS/PMMA, the effect of mold cavity temperature on Izod impact strength of double-gate samples is similar to that of single-gate samples. However, for ABS/PMMA/nano-$CaCO_3$, Izod impact strength increases gradually with increasing mold cavity temperature firstly. And the Izod impact strength becomes to decrease when mold cavity temperature is higher than 125°C. With the increase of mold cavity temperature, the viscosity of melt becomes lower and lower. Then resin phase can flow freely in the mold and wrapped $CaCO_3$ particles. Thus content of $CaCO_3$ particles at weld line is decreased and the weld line strength will be increased significantly.[6] Therefore, effect of mold cavity temperature on Izod impact strength of double-gate samples is different from that of single-gate samples for ABS/PMMA/nano-$CaCO_3$. Both tensile and Izod impact strengths of ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ samples become to decrease when mold cavity temperature is higher than 125°C.

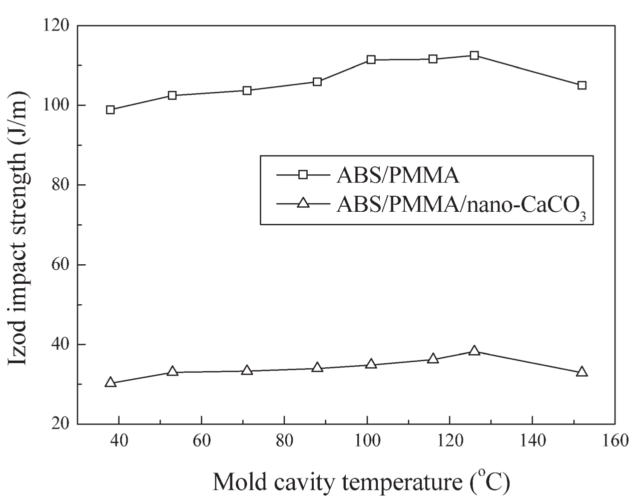

Figure 13. Effect of mold cavity temperature on Izod impact strength of double-gate samples.

CONCLUSIONS

In RHCM process, surface quality of plastic parts can be improved significantly by increasing mold cavity temperature. The gloss of both ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ gradually increase with the increase of mold cavity temperature. Incorporation of nano-$CaCO_3$ particles causes the deterioration of surface quality of plastic parts. However, the surface quality of ABS/PMMA/nano-$CaCO_3$ parts is improved significantly in RHCM process by increasing mold cavity temperature. The roughness and gloss of two kinds of plastic parts (ABS/PMMA and ABS/PMMA/nano-$CaCO_3$) stabilized at the same level when the mold cavity temperature is above glass transition of resin material. In addition, weld line can be eliminated in RHCM process during high mold cavity temperature.

The tensile strength of both sing-gate and double-gate samples (for both ABS/PMMA and ABS/PMMA/nano-$CaCO_3$) exhibit decreasing trend with the increase of mold cavity temperature since the degree of polymer chains' orientation is reduced. In RHCM process, reduction of internal stress gives rise to the increase of Izod impact strength of ABS/PMMA for both sing-gate and double-gate samples.

Izod impact strength of ABS/PMMA/nano-$CaCO_3$ decreases slightly due to uneven distribution of nano-$CaCO_3$ particles in single-gate samples. However, Izod impact strength of ABS/PMMA/nano-$CaCO_3$ increases slightly with the increase of mold cavity temperature due to less nano-$CaCO_3$ particles in weld line in double-gate samples. For all the samples in this study, too high of mold cavity temperature (higher than 125°C) depraves the Izod impact strength of plastic parts. Both ABS/PMMA and ABS/PMMA/nano-$CaCO_3$ are not susceptible to weld line.

When the mold cavity temperature is approximately equal to glass transition temperature of resin material, all the samples are found to give the best combination of properties. When mold cavity temperature is higher than glass transition temperature of resin material, there is no further increase in surface and mechanical properties of ABS/PMMA and ABS/PMAM/nano-$CaCO_3$. Higher mold cavity temperature will increase injection cycle time and production cost. Thus glass transition temperature is the optimal temperature for mold cavity in RHCM process.

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