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Fiber Orientation of Polymer Injection Weld and Its Strength Evaluation

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This paper discusses the microstrure related fracture behavior of short-fiber reinforced thermoplastics. The microstructure of an injection molded weld was studied by microscopic methods for the purpose of describing fiber orientation. Injection welds are the place where two flow fronts come together, leading to fiber orientations having flower and volcano-like patterns. The polymer composite materials used in the experiment were polycarbonate(PC) with amorphous structure containing 30% short glass fiber and polyphenylene sulfide(PPS) with crystalline structure containing 40% short glass fiber. The specimen used was a dumbbell type tensile specimen with a weld line created by double gate injection molding. Microtoming technique was used for slicing ultrathin sections from the molded polymer parts. Microstructural analysis of fiber orientation at injection weld was carried out using light transmission microscopy(LM) and scanning electronic microscopy(SEM).

Key Words : Fiber Orientation, Polymer Injection Weld, Polycarbonate, Polyphenylene Sulfide, Microtoming Technique, Tensile Strength, V-Notch, SEM

1. Introduction

Engineering plastics, such as advanced polymer composites, have been developed intensively over the past decade because of the great potential benefits of these materials in airplane and automobile primary structural applications and in electronic packaging.

Thermoplastic injection moldings form the weld line because of the presence of cores, pins, corners and multiple gates that divide the polymer melt during flow in the mold. This is a weld region where two flow fronts come together. Formation of weld line in injection molded products is practically unavoidable (Grafton, 1975 ; Wool, 1989 ; Malgurnera, 1981 ; Tadmore, 1979).

Thermoplastic injection moldings are used in many applications, and then, there are some problems to be solved in weld line. The weld line looks somewhat like a V-notch and cracks and also leads to reduced strength. So safety considerations and design reliability have stimulated an increasing interest in understanding and predicting failure mechanisms of polymer composites, especially in the injection weld.

Several other researchers have studied the effect of the weld line on the mechanical properties of a specimen. Malgurnera and Manisali(1981) studied the effect of melt temperature, mold temperature, injection speed and injection pressure on the tensile properties of commercial grades of polystyrene, high-impact polystyrene and polypropylene. Their results indicated that the most important processing parameters seemed to be the melt and mold temperatures. Injection speed and pressure had little effect on the tensile properites.

According to Kim and Suh(1986), the weakness of the weld line can be attributed mainly to the following three factors ; 1) incomplete bonding at

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the interface of two flow fronts ; 2) the frozen-in molecular orientation caused by a fountain flow at the flow front, remaining parallel to the interface ; and 3) the existence of a V-notch around the weld line surface caused by entrapped air or contaminants. They analyzed the first and the second factors separately and then integrated them to predict the strength of a weld line at given processing conditions and cavity geometry.

Therfore, in this study the effect of glass fiber orientation at weld line and the bulk without weld on mechanical properties have been studied by tensile test, LM and SEM. In addition, there have been studied on relation between orientation of glass fiber and polymer matrix by image analysis.

2. Experiments

The polymer composite materials used in this experiment are polycarbonate(PC) with amorphous structure representing a general engineering plastic included 30% short glass fiber and polyphenylene sulfide(PPS) with crystalline structure having 40% short glass fiber content.

A double-gated mold used in this study is shown in Fig. 1. It was for a dumbbell type tensile specimen with a weld line at the center, and also could mold a specimen without a weld line by turning valve P to close the right side gate. Molding conditions are listed in Table 1.

Microtoming techniques (Hino, 1971) for slicing ultrathin sections from molded polymer composites was used in order to analyze the orientation of glass fiber at weld line, coupled with LM, are emerging as important procedures for making an accurate microstructural analysis of fiber orientation within an injection-molded part. This kind of approach can provide the molder with information for failure analysis, part and mold design, and especially analysis of flow direction and processing optimization. The equipment needed for microtoming and sample preparation are usually available in the laboratory and can be used to prepare polymeric thin section for microstructural examination using a wheel cutter and polisher.

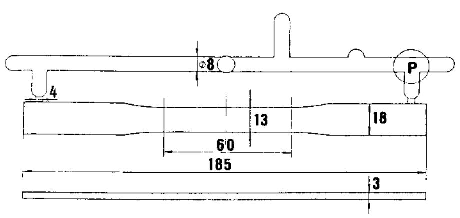


Fig. 1 Layout and dimensions of injection mold and specimens

Table 1 Injection molding conditions

	G.F Fraction (wt%)	Injection Temp. (℃)	Mold Temp. (℃)
PC (G2530)	30	320	115
PPS (C-1000SG)	40	320	135

In this study, specimens have been microtomed and polished consecutively with #200, #400, and #800 powders with a polisher ; they are then polished by hand with #2000 and #3000 alumina powder on a glass plate. The resulting sections are about 10～15 microns thick, and ready for microscopic observation.

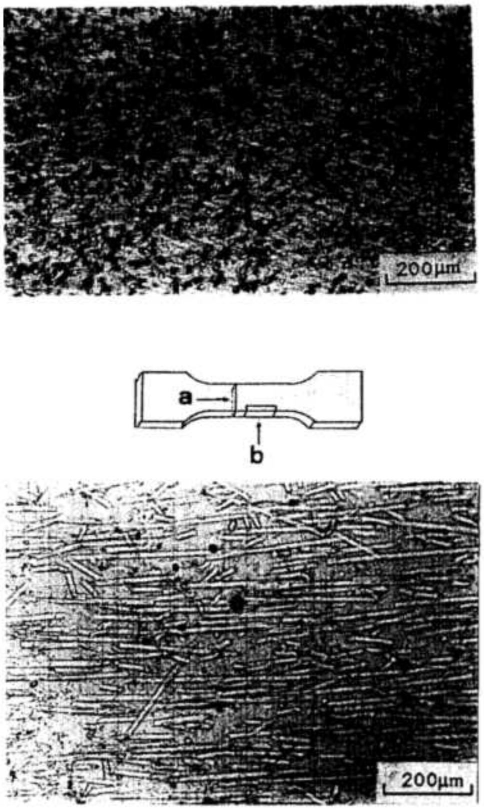
For the visualization of fiber orientation, two different methods may be used ; LM and SEM. To ensure better contrasting of glass fibers, the LM-technique was proposed recently (Bell, 1979). Fiber orientations of PC and PPS in the parent and weld were observed by LM with the ultrathin (10～15 microns) sections. Also, the fracture surfaces of the specimens were observed by SEM at an acceleration voltage of 10 kV.

3. Results and Discussion

3.1 Microstructure of parent and weld

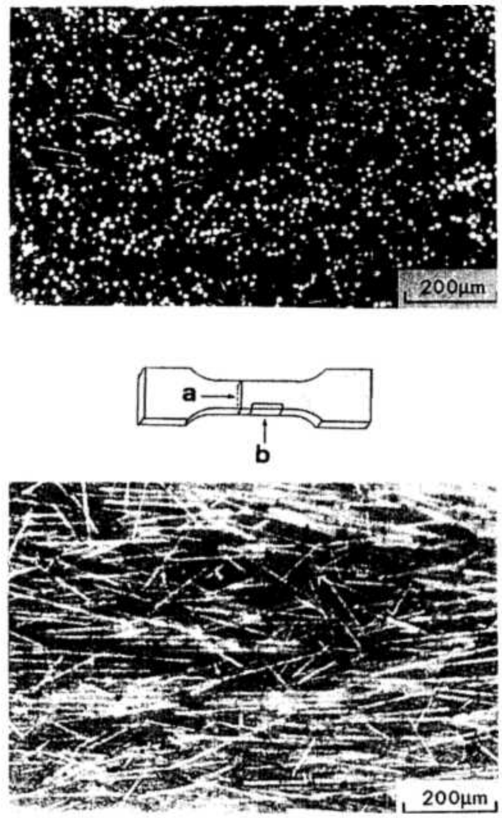
The fiber orientation pattern is highly influenced by mold geometry, processing conditions and rheological properties are affected by the viscosity and by other factors such as fiber aspect ratio, injection temperature and pressure.

As shown in Figs. 2 and 3, a detailed characterization of the phase morphology was



(b) Parallel direction

Fig. 2 Photomicrographs taken on fiber orientation of PC parent



(b) Parallel direction

Fig. 3 Photomicrographs taken on fiber orientation of. PPS parent

obtained by means of transmission microscope from sheets at orientations parallel and perpendicular to the injection flow direction. Figure 2(a,b) shows the picture of PC parent with perpendicular and parallel orientations of glass fiber, relative to the injection flow direction, respectively. The orientation of short glass fiber is the same as the injection flow, so shows the section area of glass fiber to perpendicular direction. Figure 3(a,b) also shows the picture of the PPS parent. They have nearly the same orientation of glass fiber as the PC parent, but parallel direction of PPS parent is some random of glass fiber compared with PC parent.

Figure 4 is the microstructure of PC weld showing glass fiber flow. Flows of two direction come together at one point and make a weld region. It shows the volcano-like mechanism which creates orientation at 90 angle to main polymer flow direction, comparing to flower-like pattern created at the wide area (Lim, 1992). At that time, as shown in Table 1, the temperature of melt is higher than that of mold, so mold cool down the melt and increase its viscosity at the edges of the channel thus retarding the flow. Flow at the center of channel continues at a highter rate, creating melt spill from center to edges of channel.

Figure 5 shows the photomicrographs taken of fiber orientation in the PPS weld. The fiber orientation of PPS in the weld line is perpendicular to the mold filled direction(MFD) too. The flow front is of the spherical type during injection, due to melt freezing effects in the direct vicinity of the mold surface. Especially, weld line of PPS is more than that of PC because viscosity

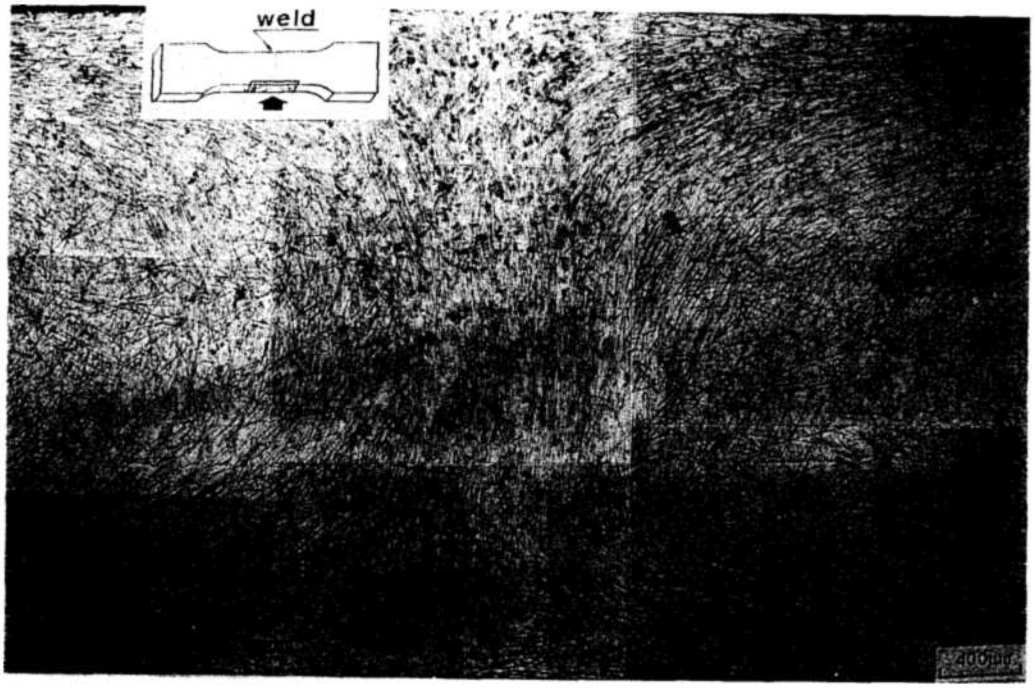


Fig. 4 Photomicrographs of volcano-like pattern of PC weld

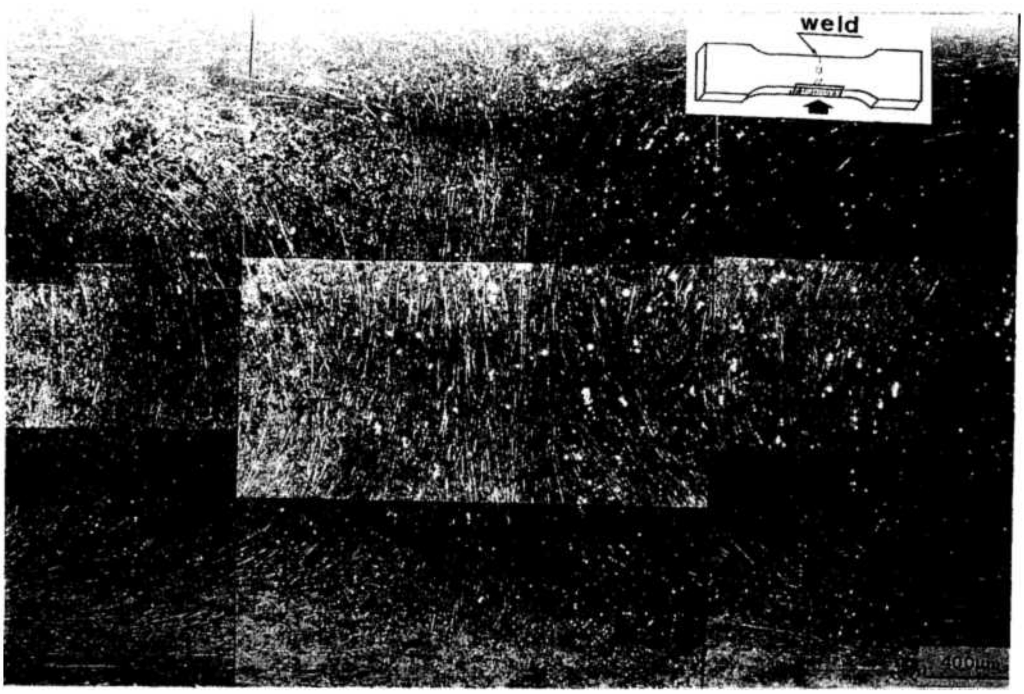


Fig. 5 Photomicrographs of volcano-like pattern of PPS weld

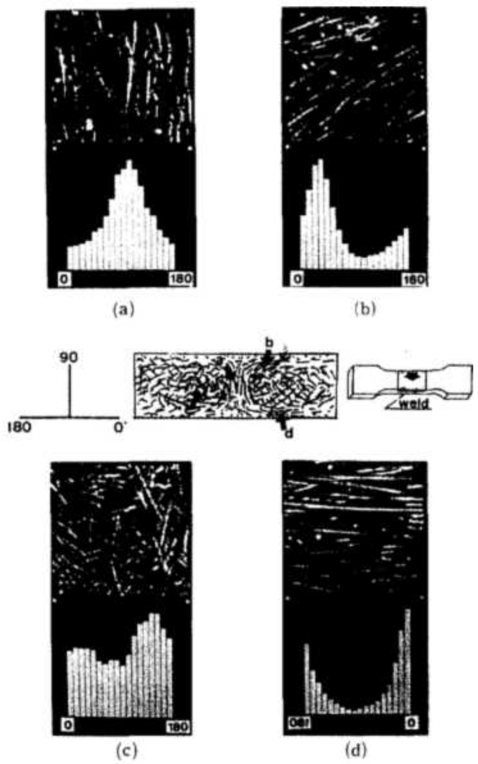


Fig. 6 Orientation analysis of glass fiber by Image Analyzer

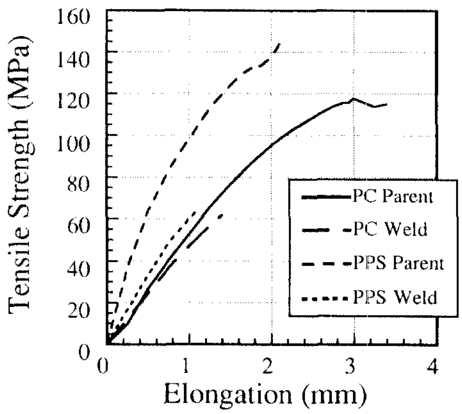


Fig. 7 Relation between tensile strength and elongation

of the melt.

Figure 6 shows the result of orientation analysis of the PPS weld by Image Analyzer. The "a" position has the glass fiber of 90 angle. Here the two flow fronts are recombining and changing the fiber orientation. In the "b" position, most of the glass fiber is at 45°, while the orientation within the "c" position is mostly 45° and 135°. At (d) the glass fibers are predominantly at 0° and 180° orientation, i.e., parallel to the MFD.

3.2 Effect of fiber orientation on mechanical properties

A major factor that weakens the weld line in injection moldings is the fiber orientation and V-notch structure (Tomari, 1990). Though the existence of a V-notch is well known, the effect of V-notch in short glass fiber-filled polymer moldings is not discussed yet. So the aim of this part is to clarify the effect of fiber orientation and V-notch on the strength of injection weld.

Figure 7 shows the relation between tensile strength and elongation of PC and PPS. As shown in Fig. 7, the presence of the weld line significantly reduces the strength of injection molded parts compared to the parent without weld line. The strength of PPS parent is 144 MPa, but that of the weld is within the half of parent, 65 MPa.

The mechanical properties of injection molded parts are affected by the microstructural anisotropies that are generated by the spatial variations of glass fiber orientation. Also, there is a yielding point in PC and PPS parent but not in the weld like high modulus materials. The results of Rockwell hardness of the parent and weld joint are 73 and 68 in the PC respectively, weldment is more milder than parent, but in the PPS an opposite trend is observed as shown in Table 2.

Typical macrofracture surfaces and contours of failure are shown in Fig. 8 for the tensile tests. Fracture surfaces of PC and PPS weld are smoother than that of the parent. The reason is the direction of fiber flow. The direction of fiber flow in the parent is parallel to the MFD and tensile direction, but in the weld specimen is perpendicular to the tensile direction.

Figure 9 shows the fracture surface of PC and PPS parent. It is easy to separate the glass fiber from matrix as show the fracture surface of PC, but it is difficult to separate the glass fiber the

Table 2 Mechanical properties of PC and PPS

Properties \ Polymer	PC		PPS	
	Parent	Weld	Parent	Weld
Ultimate Strength (MPa)	116	62	144	65
Yielding Strength (MPa)	116	62	132	65
Elongation (%)	5.7	2.3	3.6	1.9
Tensile Modulus (MPa)	3178	2800	7056	3920
Hardness (HRB)	73	68	85	94

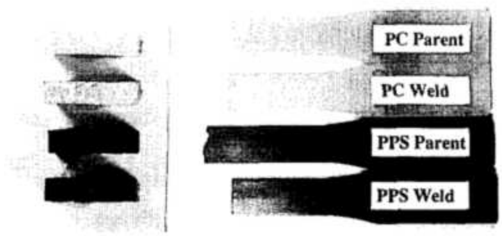
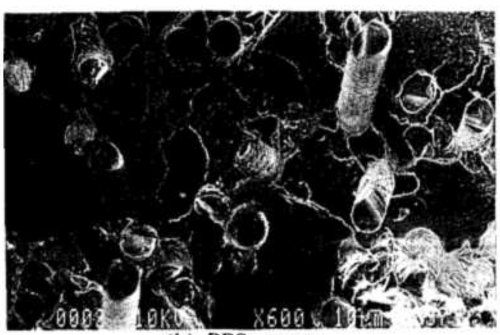


Fig. 8 Typical macrofracture surface and contour of failure for tensile tests

(a) PC parent



(b) PPS parent

Fig. 9 Comparison of fracture surface at PC and PPS parent

PPS due to creep-like to pull out the matrix. This is a major difference between PC and PPS matrix properites caused by their amorphous and crystalline structures. These agree with the results of tensile test.

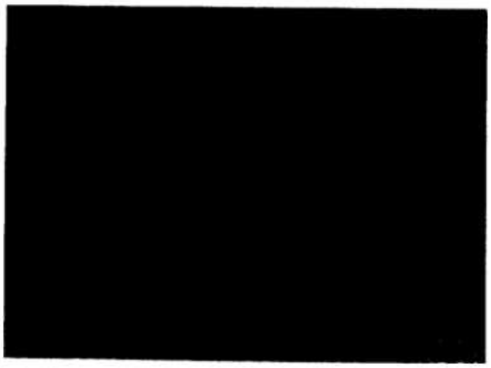
Figure 10 shows the fracture surface in the weld of PC and PPS. The orientation of glass fiber shows the difference of 90° at tensile direction. This difference of glass fiber orientation in fluences the tensile strength greatly. And the fracture mechanism that separates the matrix and glass fiber in the parent is crack mode 2, but its mechanism is crack mode 1 at the weld.

Figure 11 shows the relationship between tensile strength and section area ratio to confirm the existence of V-notch on the weld surface as generally proposed. However, the experimental results obtained here showed that tensile strength decreased with increasing Ac (section area after cutting). This means that the variations of strength at weld is dependent on the orientation of glass fiber rather than the bonding condition at weld line. Strength of the weld was effectively improved by a surface flow in the weld region to change the distribution of oriented fibers.

3.3 Effect of temperature on strength

To evaluate the effect of temperature on strength was tested at range of -60℃ to $+100$℃. Low temperature was controlled by liquid nitrogen and high temperature by heating coil in air.

Figure 12 shows the effect of temperature on tensile strength of PC and PPS. Tensile strength



(a) PC weld

(b) PPS weld

Fig. 10 Comparison of fracture surface at PC and PPS weld

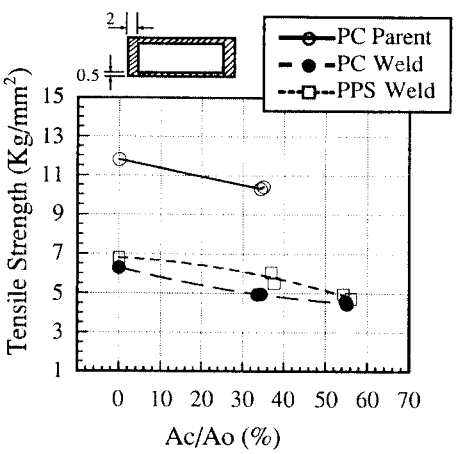


Fig. 11 Relationship between tensile strength and section area ratio

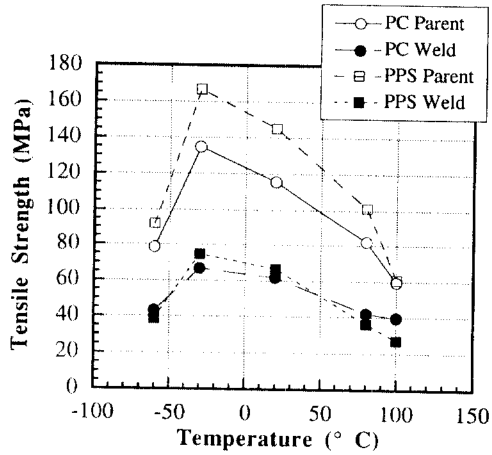
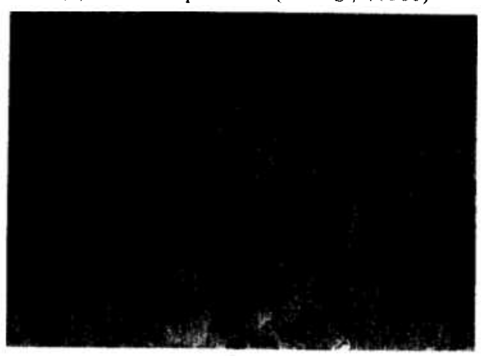


Fig. 12 Tensile strength of PC and PPS with the changes in temperature

(a) Test temperature (−60℃, ×300)



(b) Test temperature (100℃, ×300)

Fig. 13 Difference of micrograph depending on temperature at PPS parent

at room temperature is lower than that of −30℃. It is reasonable to assume that interface force of matrix and fiber at −30℃ is stronger than that at room temperature, it is the effect of thermal shrikage force at −30℃. The effect of temperature on tensile strength in the parent is greater than that

(a) Test temperature (−60℃, ×1000)

(b) Test temperature (100℃, ×1000)

Fig. 14 Difference of micrograph depending on temperature at PC welded specimen

of the weld because strength of the parent depends on the matrix and the weld is dependent upon fiber orientation. Figure 13 shows the fracture surface of PPS parent fractured at −60℃ and +100℃. Both can not find the debonding of the fiber and the matrix because the effect of shrinkage at low temperature of −60℃ and the expansion at high temperature of +100℃.

Figure 14 is the fracture surface showing the difference depending on the temperature of PC welded specimen, (a) is the fracture surface at −60℃, brittle and cleavage-like fractography, but (b) is the mild fractography at 100℃. This result shows that the matrix is brittle and break first at low temperature but glass fiber is breaking first and continuing to matrix at high temperature.

4. Conclusions

The conclusions derived from the experimental results on the weld line of PC and PPS injection moldings are summarized as follows.

(1) Microstructure and fiber orientation of PC and PPS are depending on the position of mold, especially, weld of them, which is the place where two flow fronts come together has tber orientation of volcano-like pattern.

(2) The change of the tensile strength at parent as the temperature varies is higher than that of the weld. And the strength at low temperature of −30℃ is 16% higher than that of room temperature, and the strength within and over the this temperature is decreasing with the temperature.

(3) The strength decrement at weld is affected more significantly by the fiber orientation than the bonding condition such as V-notch at weld line.

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