

Effect of Thickness on Weld Line Strength of Injection Molded Thermoplastic Composites

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ABSTARCT

The injection molding of thermoplastic composites has become an important process, especially in the automotive industry, due to high-volume production rates and their ability to be molded into complex shapes. However, there are still several unresolved problems that confound the overall success of this technology. Among them, weld lines are the most prevalent, occurring in most injection-molded parts, except those with very simple geometry. The formation of a weld line is regarded as one of the most undesirable phenomena, especially in injection-molded, fiber-reinforced thermoplastics, since it may result in poor appearance as well as poor mechanical properties. The focus of this study was to determine the effect of component thickness on the weld line strength of injection-molded, short-fiber-reinforced, thermoplastic composites. Comparisons were also made with injection-molded parts without weld lines. The use of design data, which take into account fiber orientation as well as thickness, will enable design engineers to predict more accurately the performance of a molded part under applied load.

Key words: weld line strength, thermoplastic composites, injection molding, wall thickness, skin and core layers

INTRODUCTION

Injection molding is one of the most attractive industrial polymer processes industry. It is especially used to produce in a single operation a wide variety of articles with complex geometry. Other advantages include a high production rate and a low percentage of scrap. Thus, this process is very attractive from an engineering and economical viewpoint. However, molding complicated parts, multiple gates and cavities containing inserts may generate serious difficulties in terms of mold filling and in turn affect the properties of finished products. In fact, molding

of such parts usually produces a weld line once the melt fronts either join by impingement flow or flow around an insert.

Weld lines look like cracks on the surface of the molded part. These crack-like features are often visible to the naked eye and as a result are considered aesthetically unacceptable in many applications. More importantly, the local mechanical strength in the area of the weld can be significantly lower than the strength away from the weld, especially in fiber-reinforced thermoplastic systems. Many authors (Savadori *et al.*, 1983; Fisa and Rahmani, 1991; Vaxman *et al.*, 1991; Meddad and Fisa, 1995; Zhou and Mallick,

2006) have studied weld lines in injection-molded, thermoplastic composites. Savadori *et al.* (1983) studied the weld line strength of PP filled with inorganic particles, and proposed that the weld line strength depended on the content and the shape factor of the filler. Fisa and Rahmani (1991) investigated the weld line zone of injection-molded, glass-fiber-filled polypropylene (PP) composites. They found that the weld line was a zone between 2 and 8 mm wide extending throughout the thickness in which the fibers were oriented almost perfectly in a plane parallel to the weld line. In addition, Meddad and Fisa (1995) also found that the weld line strength of molded composites decreased with increased fiber content. Vaxman *et al.* (1991) investigated the weld lines in short-fiber, reinforced, thermoplastic materials. They suggested that the orientation of the fibrous reinforcement, which is parallel to the weld interface, caused a significant reduction of the tensile strength compared to the injected parts without a weld line. Zhou and Mallick (2006) presented the experimental results of stress-controlled fatigue tests on an injection-molded, 33 wt%, short, E-glass, fiber-reinforced polyamide 6,6. The effects of specimen orientation with respect to the flow direction and weld line on the fatigue life were considered. They found that the modulus, tensile strength and the fatigue strength of the material were significantly higher in the flow direction than normal to the flow direction, indicating inherent anisotropy of the material caused by flow-induced orientation of fibers. The presence of a weld line significantly reduced the modulus, tensile strength, failure strain and fatigue strength. In order to increase the weld line strength of injection molded parts, especially for injection-molded, thermoplastic composites, some special injection-molding techniques such as SCORIM (Shear Controlled Orientation Injection Molding), sequential injection molding and push-pull injection molding have been proposed to eliminate and/or heal weld lines. Furthermore, these techniques can also be used to control both

molecular and fiber orientation (Bevis *et al.*, 1998; Kühnert *et al.*, 2005; Patcharaphun *et al.*, 2006).

The focus of this study was to investigate the effect of the thickness of a part on the weld line strength of injection-molded, short-fiber-reinforced, thermoplastic composites. The material used was 30% short-glass-fiber-filled polypropylene composite. After molding, the weld line strength of the parts was determined by impact and tensile tests. Specimens with various thicknesses of 2, 4 and 6 mm were studied in terms of their influence on the weld line strength. For the sake of comparison, the experiments were also carried out with injection-molded parts without weld lines to help provide a basic understanding for design engineers to predict more accurately the performance of a molded part under applied load.

MATERIALS AND METHODS

This study used commercially available, grade material, 30% short-glass-fiber-filled PP composite (Global Connections Public Co., Ltd., Thailand). Experiments were conducted with an injection-molding machine (Arburg allrounder 320C, Germany). For this study, a special injection mold was designed and constructed (Figure 1) in order to produce specimens of various thicknesses (from 2 to 6 mm). The specimens with a weld line at the center were obtained by double gate molding and the specimens without a weld line were obtained by single gate molding, as illustrated in Figure 2. The material was dried according to the recommended temperature and drying time prior to the injection process. All the specimens were processed after the machine had attained a steady state at the recommended melt and mold temperatures. The mold temperature was kept at 30°C and the five heating zones (from nozzle to feed zone) were set at 230, 220, 210, 200 and 190 °C, respectively. Low screw speeds and back pressure were used to minimize fiber breakage. After molding, the plates (with and without weld

lines) were milled into miniaturized tensile specimens (Figure 2) in accordance with the ASTM D638 procedure. Impact bars were obtained from the tensile bars by removing the clamping parts, referring to the standard of ASTM D256. The tensile samples were tested on a Hounsfield universal testing machine with a crosshead speed of 50 mm/min for a sample gauge

length of 60 mm. IZOD impact tests were conducted on a Gotech impact tester model GT-7045 with an impact energy of 1 joule and a sample span length of 60 mm. The average values of maximum tensile strength (MPa) and impact strength (kJ/m^2) were obtained from a group of five specimens. Optical microscopy (OLYMPUS model PMG3) and computer aided image analysis

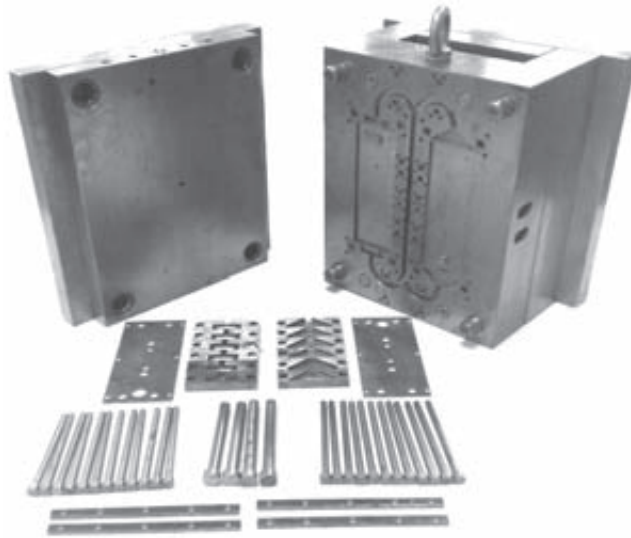


Figure 1 The injection mold used in the study.

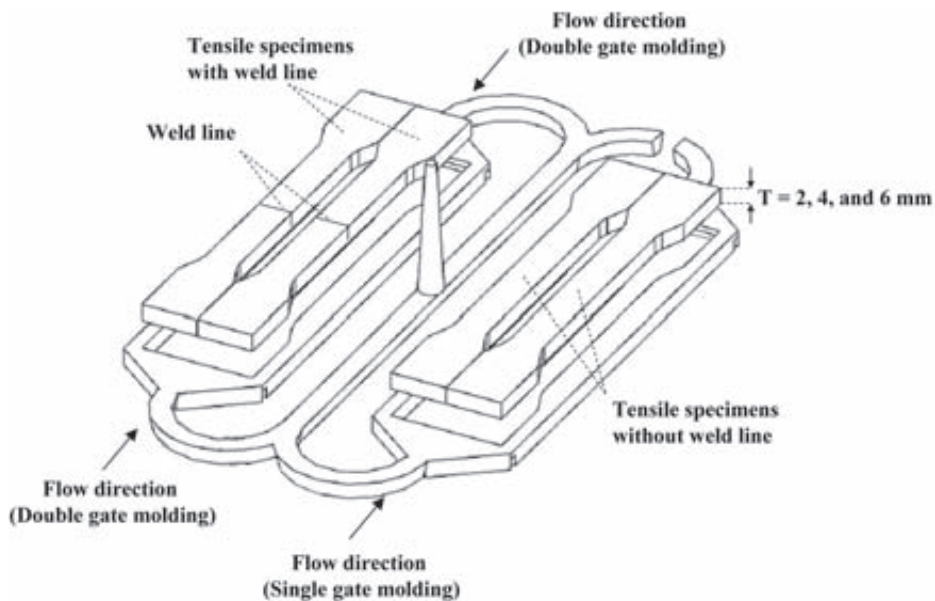


Figure 2 Schematic representation of the filled article and the location of tensile bars with and without a weld line.

(Image-Pro Plus) were utilized in order to investigate the thickness of the skin and core layers developed within the injection-molded specimen. To observe the thickness of skin and core layers, the specimens were cut perpendicular to the flow direction at the weld line location and mounted on a microscope after polishing by a metallurgical polishing technique.

RESULTS AND DISCUSSION

The impact and maximum tensile

strength of injection-molded, 30% short-glass-fiber-filled PP with and without a weld line are shown in Figures 3 and 4. It can be seen that the impact and maximum tensile strength of the samples with a weld line were significantly lower than the values obtained from the samples without a weld line. As shown in Figure 5, it was found that there were two distinct regions with different fiber alignments across the thickness of the non-weld line specimen. This had been identified also by other studies (Singh and Kamal, 1989; Akay and Barkley, 1991; Gupta and Wang, 1993;

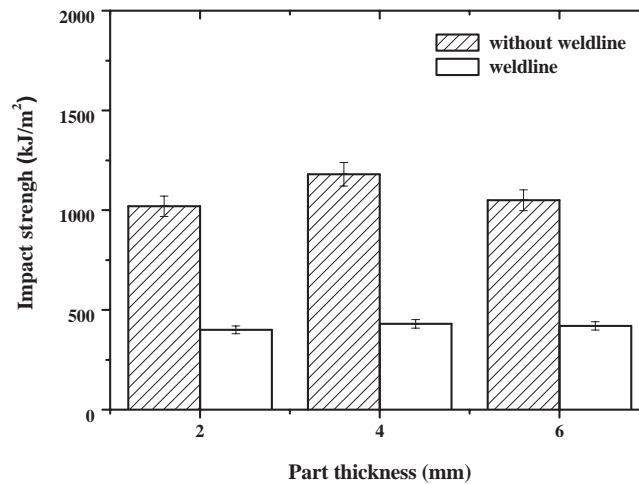


Figure 3 Impact strength of specimens with and without a weld line for different part thicknesses.

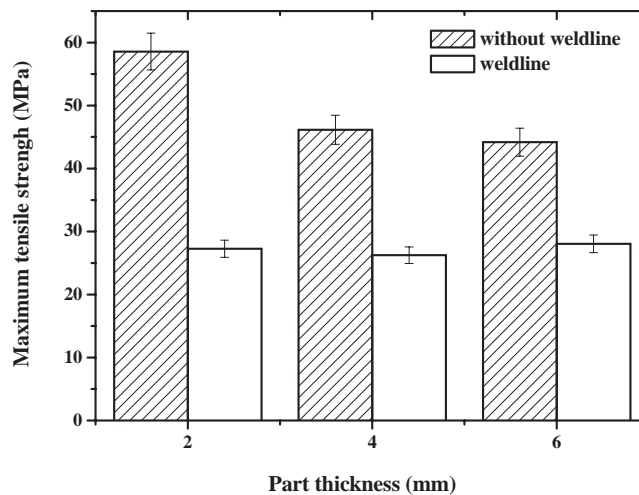


Figure 4 Maximum tensile strength of specimen with and without a weld line for different part thicknesses.

Barbosa and Kenny, 1999; Larsen, 2000). In the layer near the mold wall, referred to as the skin layer, the fiber orientation was predominately parallel to the flow direction. This was due to elongational forces arising during fountain flow at the front and to shear flow after the front has passed. In contrast, a random in-plane alignment of fibers was observed in the core layer due to a slower cooling rate and lower shearing force during the flow. The reduction in strength of a weld line containing specimens would be related to the thicker core layer including the voids at the weld line interface and the existence of V-notches at the weld line surface, as illustrated in Figures 6 and 7. The thicker core layer in the weld line region was caused by the fountain flow near the melt front, as fibers from the core region near the melt front moved outward to the wall, passing through the fountain region; moving away from the weld line zone, the fiber orientation pattern was similar to that observed in the non-welded specimens. The existence of voids and V-notches was mainly attributed to air entrapment during a head-on impingement of two melt fronts without additional flow following. These can be a source of weakness

and thus it would be easy to break at this position when compared to another position away from the weld line area. This observation was also in accordance with many authors (Fisa and Rahmani, 1991; Vaxman *et al.*, 1991; Medda and Fisa, 1995; Patcharaphun *et al.*, 2006).

In Figure 4, accounting for the standard deviation, the results obtained for the specimen without a weld line revealed no significant change in the impact strength as the thickness increased. However, from Figure 4, it should be noted that the tensile strength for the specimen without a weld line tended to decrease as the wall thickness increased from 2 to 6 mm. The decrease in tensile strength resulted from the build up of the core layer as thickness increased, as shown in Figure 8. The core layer represents an area where the fibers are preferentially oriented perpendicular to the flow or load direction resulting in isotropic mechanical behavior (Akay and Barkley, 1985; Lian *et al.*, 1995; Gerard *et al.*, 1998; Patcharaphun *et al.*, 2006). With respect to the effect of thickness on the weld line strength of injection molded PP composites, it should be noted that an increase in the thickness does not lead to significant changes

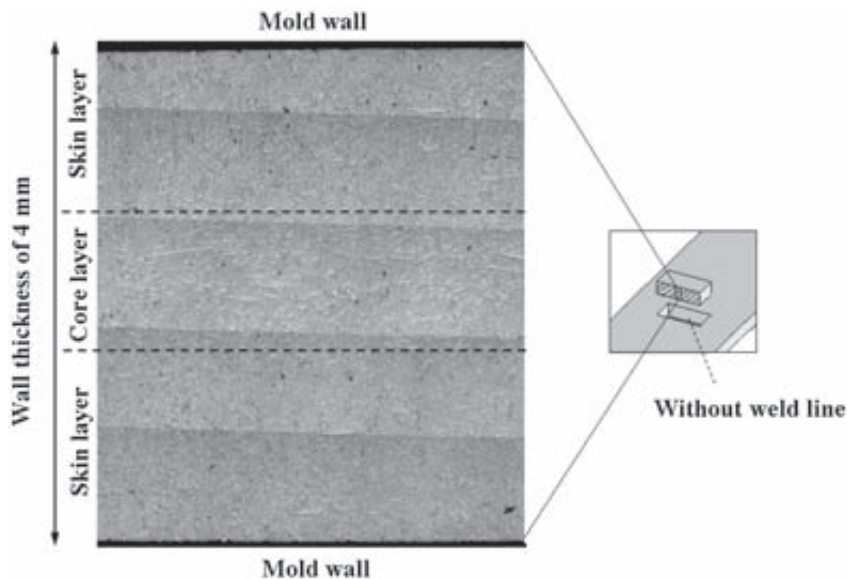


Figure 5 Optical micrographs showing the fiber orientation pattern across the 4 mm thickness of a non-weld line specimen (cross-sectional area).

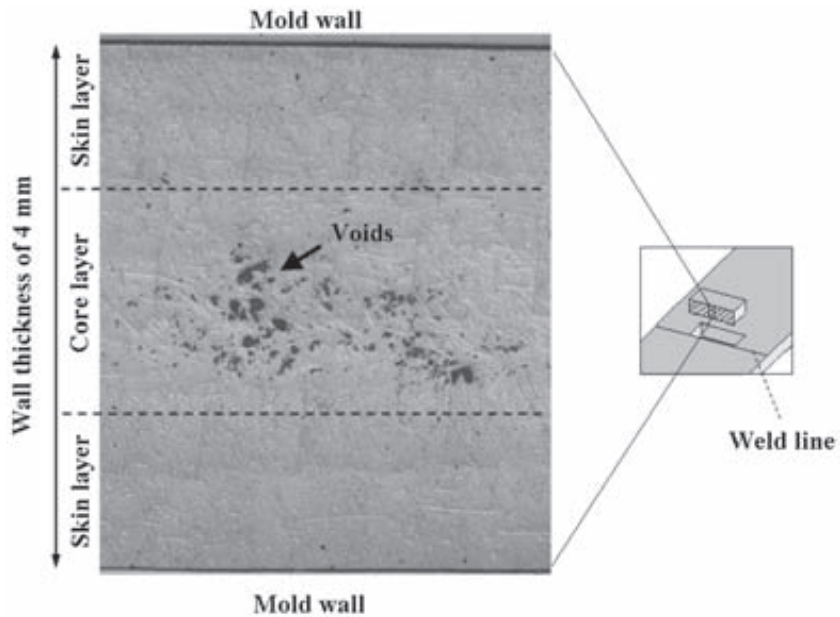


Figure 6 Optical micrographs showing the fiber orientation pattern across the 4 mm thickness of a weld line specimen (cross-sectional area).

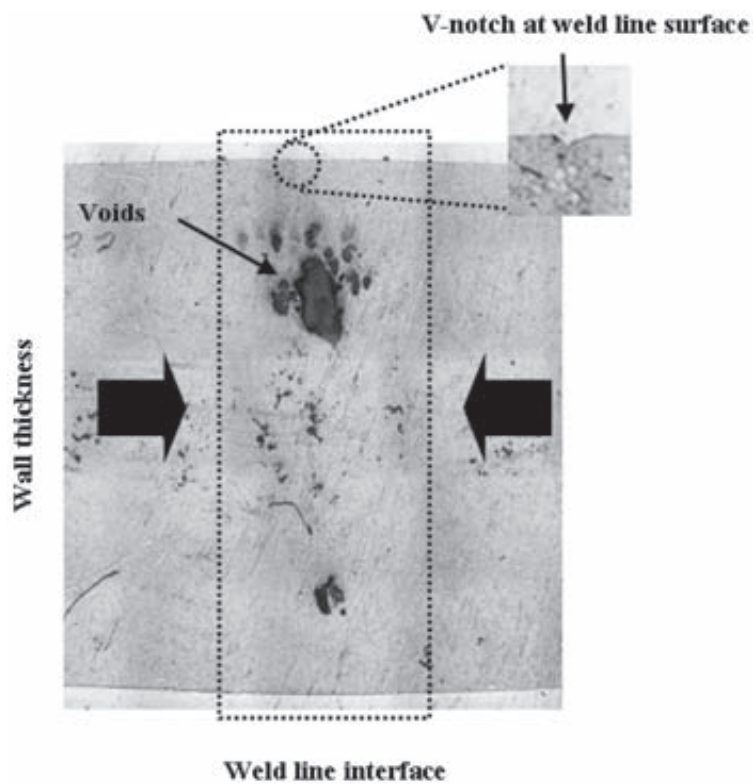


Figure 7 Optical micrographs showing the presence of voids and V-notches at the weld interface (longitudinal area).

in the impact and tensile strength. This can be attributed to the thickness of the skin and core layers remaining unchanged, particularly in the core layer, as presented in Figure 9.

CONCLUSIONS

In this work, the influence of the thickness of a component on the weld line strength of injection molding short-glass-fiber-reinforced PP was investigated. The impact and tensile strength of specimens containing a weld line were significantly lower than the values obtained from specimens without a weld line. The results obtained for the specimen without a weld line revealed that no significant change occurred in the impact strength, whereas the tensile strength

tended to decrease as the wall thickness increased from 2 to 6 mm. Furthermore, the results obtained from this investigation also indicated that an increase in the thickness of specimens did not produce any major changes in the weld line strength of injection-molded PP composites.

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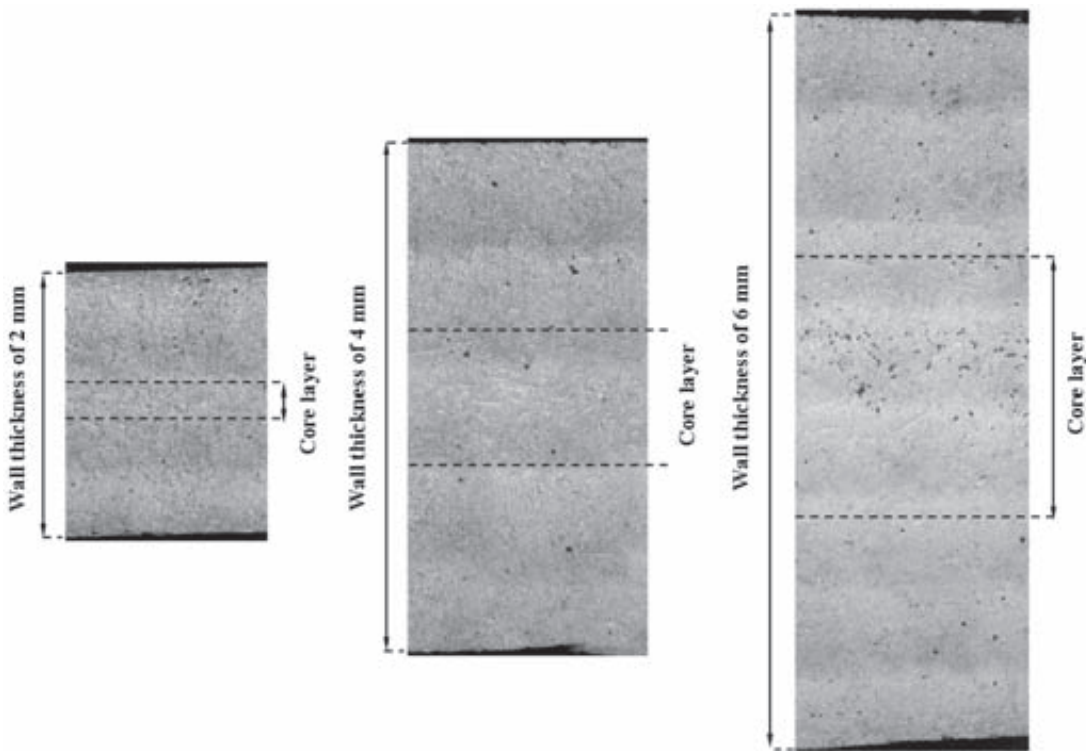


Figure 8 Optical micrographs showing the thickness of the core layer developed across the thickness of non-weld line specimens: (a) thickness of 2 mm; (b) thickness of 4 mm; and (c) thickness of 6 mm.

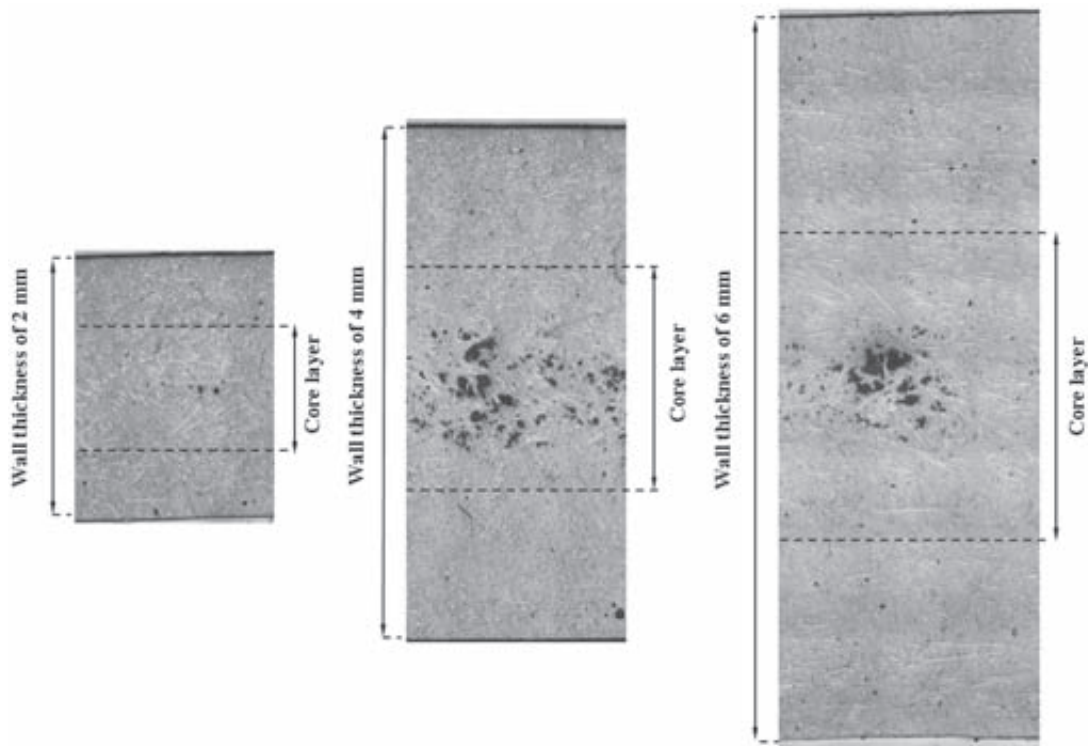


Figure 9 Optical micrographs showing the thickness of the core layer developed across the thickness of weld line specimens: (a) thickness of 2 mm; (b) thickness of 4 mm; and (c) thickness of 6 mm.

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