Weldability Evaluation on Effects of Filler Content of Polypropylene Copolymers for the Electromagnetic Welding Process

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Abstract

The weldability using the electromagnetic process has been evaluated for different grades of polypropylene copolymers being used for automotive and domestic applications. As previous publications [1 – 2] have revealed, the electromagnetic welding process has demonstrated its robustness on various resins and applications.

In this paper, comparative study between the vibration welding process and the electromagnetic welding process has been performed to evaluate effects of filler (talc and glass) content on weldability for polypropylene copolymers.

Extensive DOE procedures to optimize the vibration welding process and electromagnetic welding process have been performed. In Ref. [3], a definition of weldability for the material has been suggested. For more conclusive evaluation, both welding strength and failure modes of the welded plaques need to be investigated. The same definition for weldability has been used for this study.

In this study, it has been found that talc and glass content adversely affects weldability, while the electromagnetic welding process showed slightly better performance in welding strengths.

Theory

Electromagnetic Welding Process

Electromagnetic (or induction) heating results when a conductive material is placed in a varying magnetic field. The heating results from both eddy currents and hysteresis losses.

At each cycle of the applied RF field, the susceptor responds by completing the full cycle. The area bounded by the hysteresis curve is proportional to the energy converted into heat. High frequencies are required because the incremental temperature rise for each hysteresis cycle is very small (see Figure 1).

For electromagnetic induction heating, both Joule heating (eddy current losses) and magnetic heating (hysteresis losses) generate energy. Benatar [4] has described that the heating of susceptor materials for the electromagnetic welding process introduces both heating effects. He also described that magnetic and eddy current intensity decreases rapidly with increasing distance of the penetration depth [4]. Figure 2 shows how heat is generated during the electromagnetic welding process.

Latest electromagnetic welding machines are using solid-state power generators such as MOSFET’s (Metal-Oxide Semiconductor Field-Effect), which can precisely control power level. In this type generator, the frequency of the magnetic field is fixed by the generator circuit and accordingly, a matching network is required to match the impedance of the generator output to that of the work coil. The control circuit of the solid state systems can be significantly more complex than conventional oscillator tube generator. But this provides sophisticated and precise control of the power output [5].

Experimentation

Materials evaluated are listed in Table 1. Five different polypropylene resins for automotive interior and domestic applications were selected to evaluate effects of talc and glass fiber content on weldability. A Design of Experimentation (DOE) matrix was developed to optimize the electromagnetic welding process while talc and glass contents were varied to evaluate effects on weldability. Ten data points were generated to cover data variation during the tests. Weldability for this study has been determined using the following:

- Weld strength
- Elongation
- Fracture surface classification of plaques after tensile testing

Two 50x100x2.5mm plaques were injection molded and cut into 50x2x2.5mm as shown in Figure 3. Figure 4 shows how test fixtures were designed and the tensile test was performed.

Results

Effect of Talc Content on Welding Strength

Resins A, B, and C have talc contents of 20%, 30%, and 40% respectively. Average weld strengths of the three resins are summarized in Table 2. Figure 5 shows distribution of test data for three resins. When talc content was varied from 20% to 30% and 40%, the welding strength was reduced by 20.1% and 32% respectively. Figures 6 and 7 show cross sectional views of electromagnetic welded samples. As the figures show, when the welding parameters are fully optimized, electromagnetic susceptor materials are fully mixed with and diffused into parent plaque materials. Figure 8 shows a more magnified view of the mixture and diffusion of susceptor and parent materials. When process parameters were fully optimized, the welded plaques were broken through the parent material, which led the higher welding strength.

From a previous study released [3] for similar polypropylene, when the talc content was varied from 20% to 30%, the welding strength was reduced by 25%. Additional tests for the vibration welding strength for this study also showed that when talc content was varied from 20% to 30% and 40%, the welding strength was reduced by 23% and 38% respectively. Figure 9 shows typical sectional views for the vibration welded joint area. As Figure 9 shows there exist narrow aligned material flow regions (see more zoomed view in Figure 10). This aligned material flow area will affect the welding strength when higher contents of filler exist. This can be a reason for slightly more reduction of the welding strength, when the vibration welding process is compared with electromagnetic welding process.

Effect of Talc Contents on Elongation

Figure 12 shows the distribution of tensile elongation for talc content variations. Among 10 samples tested, sample number 4, 8, and 9 were broken at parent material away from weld joint area, which resulted in a much higher elongation value. For calculating the average elongation rate, those three data points were eliminated. Table 3 summarizes elongation amount during tensile tests. When talc content was varied from 20% to 30% and 40%, the elongation amount was decreased by 13% and 34% respectively. V. Kagan and R. Nichols have found similar results in their previous study [1].

Effect of Glass Content on Weld Strength

Resins D and E contain 20% and 30% of glass reinforcement by weight. Average weld strengths of the two resins are summarized in Table 4. When glass content was varied from 20% to 30%, the welding strength was decreased by 6%. Tests for the vibration welding process have shown that the welding strength was reduced by 3%. Therefore the effect of glass content on welding strength for the vibration welding process was slightly better than the electromagnetic welding process. The vibration welding strength for 20% and 30% glass content, however, was less than that of the electromagnetic welding strength by 21% and 18% respectively. As discussed in previous section, aligned material flow regions at the vibration weld joint area affect the weld strength more adversely.

Effect of Glass Content on Elongation

As summarized in Table 4, higher glass content results in reduced elongations during tensile tests. When glass content was varied from 20% to 30%, elongation was reduced by 6%.

Evaluation of Fracture Surface

For different types of resins under different welding conditions, samples with higher welding strength and elongation always showed very ductile broken surfaces, and the welded samples were broken at the parent material rather than at welded joint areas.

Conclusion

Effect of Talc Contents

As is normal for all welding processes, an increase of talc content adversely affects both welding strength and elongation significantly. Tables 2 and 3 summarize the results for 20%, 30% and 40% talc content. In comparison with the vibration welding process, effects on welding strength and elongation were improved with the electromagnetic welding process.

Effect of Glass Contents

As is normal for all welding processes, increase of glass content adversely affects both welding strength and elongation significantly. Tables 4 and 5 summarize the results for 20%, 30% and 40% talc content. In comparison with the vibration welding process, effects on welding strength and elongation were improved with the electromagnetic welding process.

Acknowledgements

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Key Words

Electromagnetic welding, polypropylene, talc content, glass content, hysteresis loop, Emabond

Resin	Reinforcement Types	Reinforcement Content by weight %
A	Talc	20
B	Talc	30
C	Talc	40
D	Glass Fiber	20
E	Glass Fiber	30

Table 1 Description on resin types. All resins have the same Polypropylene matrix with the same Melt Flow Index and reinforcement types and contents are varied for the experimentation.

Talc Content	20%	30%	40%
Weld Strength (MPa)	16.9	13.5	11.5

Table 2 Welding strength vs. talc content

Talc Content	20%	30%	40%
Elongation (mm)	2.94	2.52	1.73

Table 3 Tensile elongation vs. talc contents

Glass fiber Content	20%	30%
Weld Strength (MPa)	19.6	18.4

Table 4 Welding strength vs. glass contents

Glass fiber Content	20%	30%
Elongation (mm)	3.13	2.93

Table 5 Tensile elongation vs. glass content

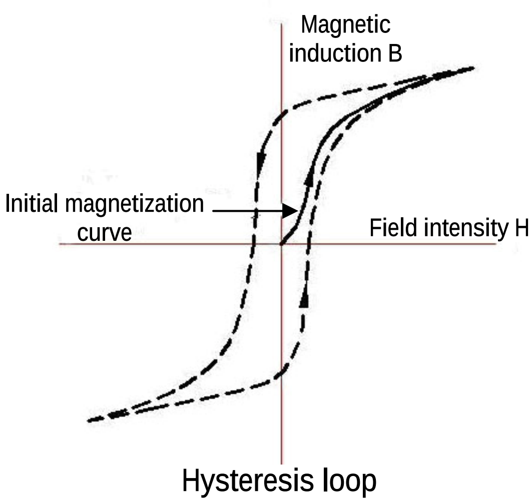

Figure 1 Hysteresis material response under electromagnetic field [1].

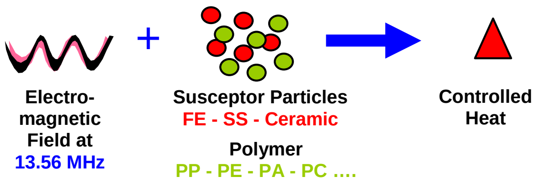

Figure 2 How heat is generated during the electromagnetic welding process [2].

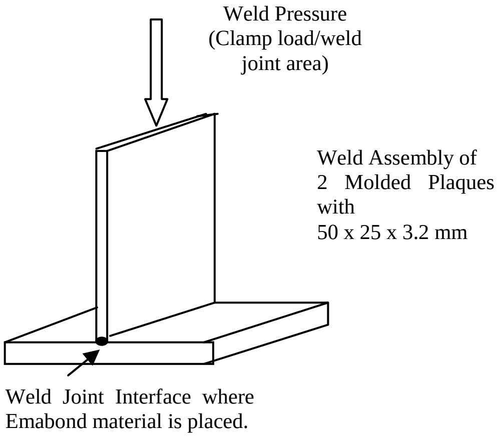

Figure 3 Welded test plaques

Figure 4 It shows how tensile test fixtures are designed and test was performed.

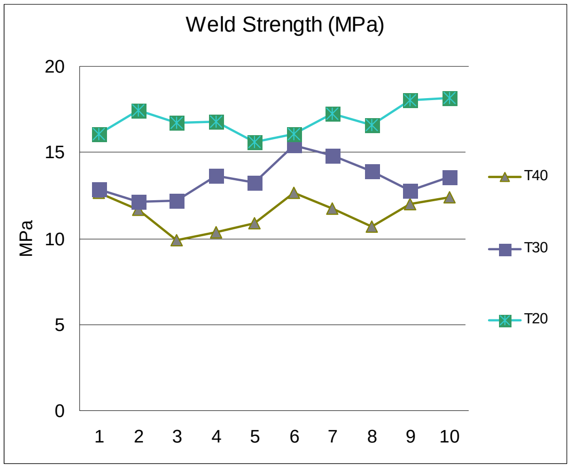

Figure 5 Welding strength distributions for Resins A, B, and C

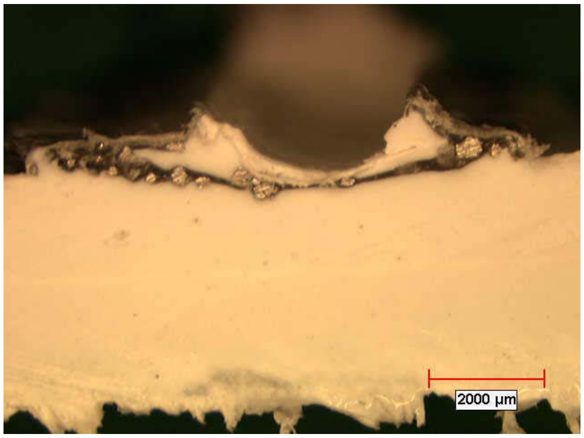

Figure 6 X-cross sectional view of electromagnetic welded sample

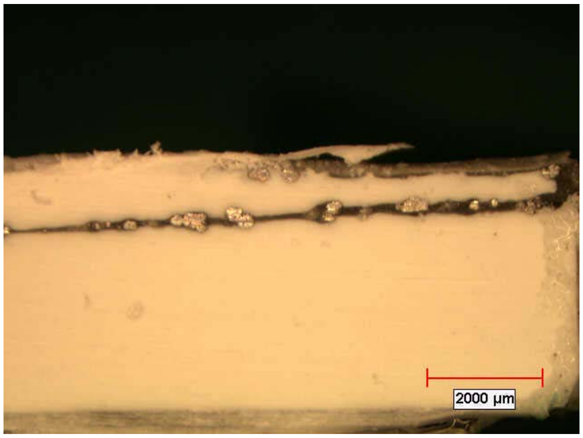

Figure 7 Y-cross sectional view of electromagnetic welded sample

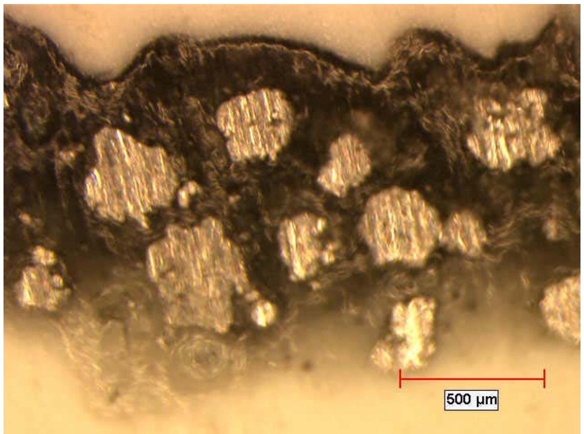

Figure 8 Magnified view of electromagnetic welded sample

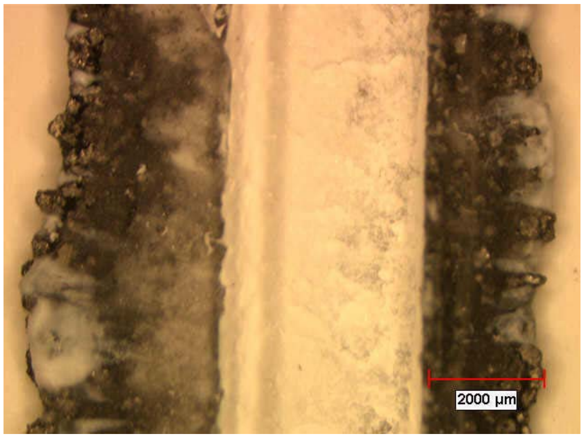

Figure 9 Broken surface of electromagnetic welded sample

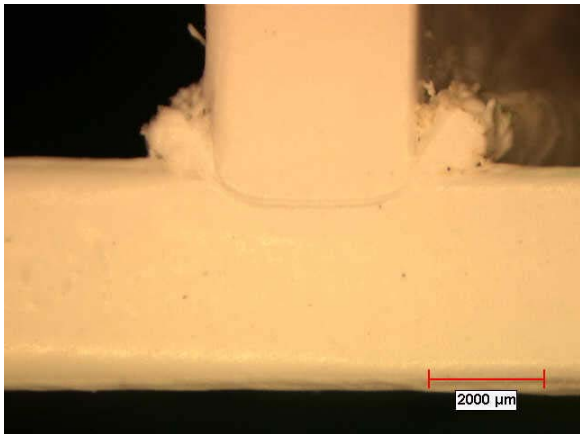

Figure 10 X-cross sectional view of vibration welded sample

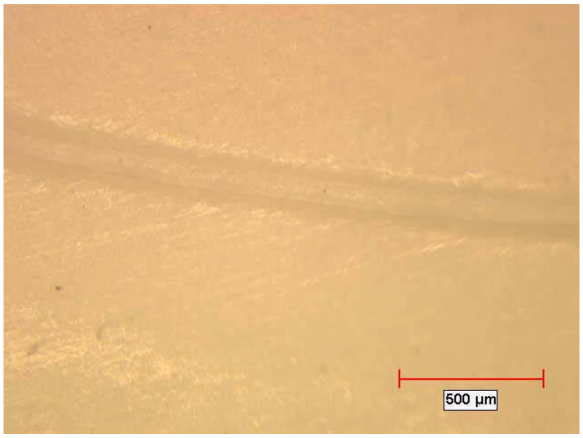

Figure 11 Magnified view of vibration welded sample

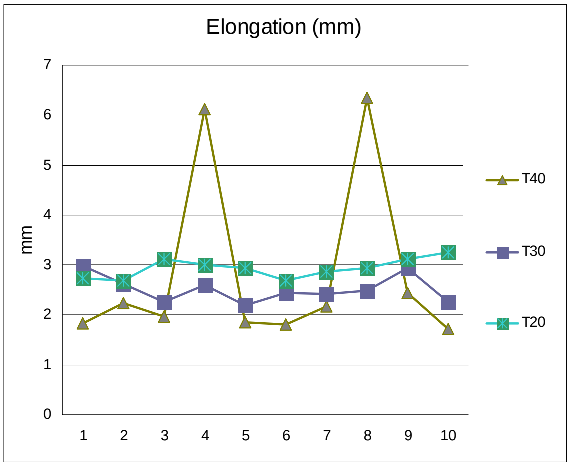

Figure 12 Elongation vs. talc contents