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LNP* Specialty Compounds

Understanding weld-line integrity

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Effect of reinforcement/filler

The location in an injection molded part where two flow fronts meet is commonly called a weld-line, though weld plane more properly describes the phenomenon. It's well known that weld-lines create weak areas in the molded part. The magnitude of this property reduction depends on the ability of the two melt fronts to knit together in a homogenous fashion during the molding process.

Predicting the integrity of the weld-line becomes more complicated when fillers and reinforcing agents are added. Still the need exists to be able to predict the amount of strength loss which can be expected prior to molding and testing the finished part. This brochure will discuss the effect of formulation, molding parameters and part geometry/mold design on the effect of weld-line integrity.

Formulation variables included
- Fillers and reinforcements — (size, configuration and amount)
- Base resin type
- Effects of polymer alloying

Processing variables included
- Melt/mold temperature
- Injection speed/pressure
- Holding (pack) time

Mold design variables included
- Part thickness
- "Butt" or head-on weld-line versus "meld" lines formed by parallel flow fronts
- Addition of overflow tabs

The test specimen used was an ASTM D638 tensile specimen as shown in figure 1. The modified runner system provided a means of molding samples with or without a weld-line with little interruption of the molding cycle. The bars were tested for tensile strength on a sintech robotest automated mechanical test machine in accordance with ASTM D638. A crosshead speed of 0.2 in./min was used for all except the non-reinforced alloyed materials which were tested using a speed of 2 in./min. Broken specimens were inspected using a scanning electron microscope (SEM) to view the orientation of the fillers and reinforcements.

Effect of reinforcement/filler
Nylon 6/6 composites containing various concentrations and several different types of reinforcements were molded and tested for weld-line strength as shown in table 1. Percent loss in strength at the weld-line is greatly increased by higher loading of fibrous reinforcement. It should be noted, however, that the absolute weld-line strength increases as the glass fiber reinforcement concentration increases.

The large drops in tensile strength are primarily the result of improper orientation of the fibers in the break area. As the flow fronts meet, the fibers are turned 90 degrees from the flow direction, which is also 90 degrees from the direction of applied stress during tensile testing. This stress is transmitted to a fibrous reinforcement through a shear mechanism along the length of the fiber. The closer the axes of the fibers align with the direction of the applied stress, the more efficient is the stress transfer. Therefore, fibers aligned perpendicular to the direction of applied force offer little reinforcing effect. This fiber misalignment is clearly seen by comparing SEM photographs of single and double gated reinforced nylon compounds in figure 2.

Figure 1

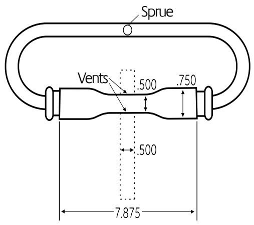
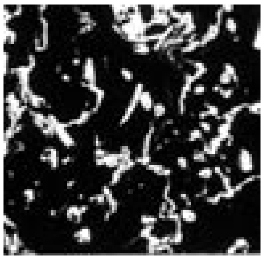
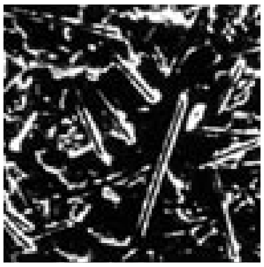


Figure 2



30% glass reinforced nylon 6/6, double gated (14,760 psi)



30% glass reinforced nylon 6/6, single gated (24,200 psi)

Particulate fillers such as talc, PTFE, milled glass and glass beads have L/D or aspect ratios considerably less than the 20:1 minimum required for optimum reinforcement. The properties of these compounds are, therefore, independent of filler orientation and behave quite similarly to the unmodified base resin (table 2). The tensile strength losses are considerably lower than with glass or carbon fiber reinforcement since these fillers do not provide significant strength enhancement to the single gated specimens. The ultimate tensile strength values across the weld-line are still higher with the use of reinforcing fibers. Filled composites behave more similarly to the unfilled base resin since the retention is independent of filler orientation.

While the low aspect-ratio fillers such as milled glass do align themselves perpendicular to the direction of applied stress, the resultant drop in tensile strength at the weld-line is slight (a loss of 8%), indicating that the properties of the 30% milled glass filled nylon are almost completely independent of filler orientation. If the filler has an aspect ratio of 1:1 (glass beads), there can be no orientation effect in the weld area and therefore, the weld characteristics are not significantly affected.

The data in table 2 also indicates that when fillers and reinforcements are combined, such as PTFE with glass fiber, the resultant drop in strength at the weld-line is approximately equal to the sum of the effects of the filler and reinforcement individually. For example, the 30% fiber glass-reinforced nylon 6/6 had 39% lower weld-line tensile strength than the comparable single gated sample with no weld-line (table 1). At the same time, the weld-line tensile strength of the 20 % PTFE lubricated nylon 6/6 was 8% lower than the same material with no weld-line. Thus one would expect a double gated test bar containing 15% PTFE and 30% glass fiber glass to have around 47% loss in tensile strength at the weld-line compared to the single-gated bar. The actual test data indicate this property loss to be 48% (52 % strength retained, see table 2). In comparing glass and carbon fibers (tables 1 and 3), both reinforcements provide for similar absolute weld-line strength values (within 1500 psi) at equivalent weight loadings. The percent loss of strength is significantly higher for carbon fibers due primarily to the higher strength that these fibers provide in single gated specimens.

Table 1 Weld-line strength vs. reinforcement type and amount in nylon 6/6

Type	%	Single gate psi	Double gate psi	% retained
–	–	11,560	11,170	97
Glass fiber	1 0	13,980	13,060	93
Glass fiber	20	19,280	14,425	73
Glass fiber	30	24,200	14,760	61
Glass fiber	40	28,830	14,990	52
Carbon fiber	30	33,500	13,400	40
Mineral	40	14,500	11,500	76

Table 2 Effects of fillers and/or reinforcements on weld-line strength of nylon 6/6

Filler	%	Reinf.	%	Single gate psi	Double gate psi	% retained
–	–	–	–	11,560	11,170	97
Milled glass	30	–	–	11,400	10,840	92
Glass beads	20	–	–	12,750	12,150	95
PTFE	20	–	–	9,630	8,860	92
Glass beads	15	Glass fiber	15	16,560	14,140	85
PTFE	15	Glass fiber	30	22,560	11,750	52
Flame retardant	10	Glass	30	22,590	13,250	59

Table 3 Effects of fillers and/or reinforcements on weld-line strength of polycarbonate

Reinf.	%	Filler	%	Single gate psi	Double gate psi	% retained
–	–	–	–	9,100	9,009	99
Glass fiber	10	–	–	11,800	10,200	86
Glass fiber	30	–	–	17,500	11,240	64
Glass fiber	40	–	–	21,000	11,600	55
Glass fiber	30	PTFE	15	16,300	9,780	60
Carbon fiber	30	–	–	20,400	9,800	48
–	–	Milled glass	30	9,300	8,700	94
–	–	Carbon powder	20	9,700	8,100	84
–	–	Stainless steel fiber	10	8,400	7,700	92

Effect of base resin

Base resins themselves have varying levels of weld-line strength retention which translates itself to the filled and reinforced grades. By comparing tables 1 and 3 it can be seen that loss in strength at the weld-line is different for nylon and polycarbonate with increasing glass loading level. The effect of the inherent weld-line integrity of the base resin on the property loss of the reinforced compounds is demonstrated by the data in table 4. Within the glass reinforced grades, the 30% glass reinforced polysulfone retains the highest percentage (65%) of its ultimate weld-line strength whereas branched PPS with 40% glass fiber had the lowest tensile strength retention at the weld at 24%. A considerable improvement in weld-line tensile strength in PPS itself can be afforded by the use of a linear PPS polymer which retains 40% of the single gated tensile strength compared with 24% for branched PPS. It can be inferred from the data that the loss of tensile strength of a composite across the weld-line is significantly affected by the base resin type. In designing with reinforced grades the important consideration is generally not percent loss but the absolute strength values.

Polymer alloying

Polymer alloys were also investigated for their relative weld-line strength retention (table 5). The effect on the weld-line retention is similar to the addition of fillers in that the tensile strength of single gated specimens is lowered with addition of the alloying agents. This proved true in the case of two nylon 6/6 wear resistant alloys (Lubriloy* compounds R & RL) based on two different alloy systems and Stat-Loy* compound A, an inherently anti-static ABS. At the same time the effect on the weld-line strength retention is similar to adding reinforcements in that the percentage loss in strength is greater for the alloys than for the unfilled base resin. The higher loss may be a result of multiple resin phases interfering with the efficiency of the bond at the weld-line. A second generation nylon 6/6 based alloy, Lubriloy RW, provides weld-line strength retention values similar to the unfilled base resin, nylon 6/6.

Table 4 Weld-line strength of glass reinforced thermoplastic resins

Thermocomp* compound	% glass	Single gate psi	Double gate psi	% retained
AF-1006 (ABS)	30	8,300	2,100	25
BF-1006 (SAN)	30	19,180	8,470	40
DF-1006 (PC)	30	17,500	11,240	64
GF-1006 (PSU)	30	15,000	9,700	65
KF-1006 (POM)	30	12,500	5,700	46
MFX-1008 (PP)	40	13,700	4,700	34
RF-1006 (PA 6/6)	30	24,200	14,760	61
OF-1008 (branched PPS)	40	25,500	6,100	24
UF-1009 (PPA)	45	38,000	12,700	33
WF-1006 (PBT)	30	16,700	9,800	40

Table 5 Effect of alloying on weld-line strength

Compound	Single gate psi	Double gate psi	% retained
R-1000	11,560	11,170	97
Lubriloy R	8,400	5,200	62
Lubriloy RL	6,700	3,200	48
Lubriloy RW	8,800	8,700	99
A-1000	6,900	3,700	54
Stat-Loy A	5,400	2,700	50

Table 6 Weld-line strength vs. injection molding conditions in Thermocomp RF-1006 (30% glass-reinforced nylon 6/6)

Parameter	Dev. from std.	Actual setting	Single gate psi	Double gate psi	% retained
Standard conditions	–	–	24,200	14,760	61
Melt temp.,°F	Increase	600	23,840	13,960	59
	Decrease	480	20,000	12,510	63
Inject. press., psi	Increase	1,500	23,900	14,420	60
	Decrease	600	23,850	14,160	59
Inject. hold time, sec.	Increase	15	23,900	14,260	60
	Decrease	2	23,850	12,160	51
Inject. rate, sec	Increase	0.5	24,150	14,680	61
	Decrease	2	22,800	13,440	59
Mold temp.,°F	Increase	250	24,140	14,360	59

Effect of molding conditions

In an earlier weld-line study completed in the 1970's no venting was initially utilized in the mold cavity at the area where the weld-line is formed. The result of this was that some materials had difficulty welding due to resistance to flow due from the compressed gasses in the vicinity of the weld formation. The mold utilized in this study contained considerable venting. A 0.001" deep by 0.5" wide vent was placed at both sides of the weld area and deepened to 0.0625" (after a land length of 0.0156") to the parting line. The vent facilitated removal of gasses from the mold cavity and prevented resistance to cavity filling from gas compression in the area of the weld. The use of a vent land length of 0.0156" prevented flashing of the weld area. It was a significant conclusion of the initial study that the use of good venting is essential to maximizing weld-line strength.

Data on the effects of molding variables on 30% glass fiber reinforced nylon 6/6 and polycarbonate appear in tables 6 and 7. Of all the variables evaluated injection hold time was the only variable shown to have a significant effect on the weld-line strength of the reinforced composites. As the holding time is lowered, weld-line strength decreases. This warrants particular attention with reinforced materials since screw barrel, and check ring wear from glass/carbon fibers may reduce the effective holding pressure transmitted into the mold cavity.

One set of materials which did show some sensitivity towards process conditions were the carbon fiber reinforced grades. When initially molded at glass fiber conditions in the weld-line plaque mold strength values were significantly lower than expected. Only when melt temperatures were raised 15–20°F (table 8) did strength values increase substantially. Carbon fiber grades increased thermal conductivity may show higher sensitivity to heat loss from long flow lengths. Higher melt/mold temperatures may be necessary with carbon fiber reinforced grades to insure maximum weld-line strength.

Geometry/design

The effect of variations in part thickness was evaluated in unfilled and reinforced versions of nylon 6/6 and PC (table 9). Weld-line strength is almost completely independent of part thickness with only minor changes strength retention as a function of thickness. Thickening the area containing a weld-line will increase a material's load carrying ability by increasing the area over which the stress is supported.

Table 7 Weld-line strength vs. injection molding conditions in Thermocomp* DF-1006 compound (30% glass-reinforced polycarbonate)

Parameter	Dev. from std.	Actual setting	Single gate psi	Double gate psi	% retained
Standard conditions	–	–	17,500	11,240	64
Melt temp.,°F	Increase	650	17,440	11,175	64
	Decrease	560	16,940	10,880	64
Inject. press., psi	Increase	11,500	17,600	11,200	64
	Decrease	600	17,580	11,100	64
Inject. hold time, sec.	Increase	15	17,720	11,870	67
	Decrease	2	17,340	10,230	59
Inject. rate, sec	Increase	0.2	17,340	11,000	63
	Decrease	2	17,320	11,080	64
Mold temp.,°F	Increase	250	16,840	11,260	67

Table 8 Effect of melt temperature on the weld-line strength of carbon fiber reinforced resins

Compound	Standard melt (550 F-nylon) (580 F PC) psi	Hot melt (570 F-nylon) (605 F-PC) psi	% increase
Thermocomp RC-1006	10,800	13,400	24
Thermocomp DC-1006	4,100	9,600	134

Table 9 Weld-line strength vs. part thickness

Compound	Reinf.	%	Filler	%	% tensile strength retained 0.0625	0.125	z0.25
Thermocomp D-1000 (PC)	–	–	–	–	100	99	99
Thermocomp DF-1002 (PC)	Glass fiber	10	–	–	91	86	90
Thermocomp DC-1006 (PC)	Glass fiber	30	–	–	64	64	65
Thermocomp DF-1006 M (PC)	–	–	Milled glass	30	100	94	92
Thermocomp R-1000 (PA66)	–	–	–	–	100	97	100
Thermocomp RF-1002 (PA66)	Glass fiber	10	–	–	92	93	87
Thermocomp RF-1006 (PA66)	Glass fiber	30	–	–	64	61	56
Thermocomp RB-1006 (PA66)							

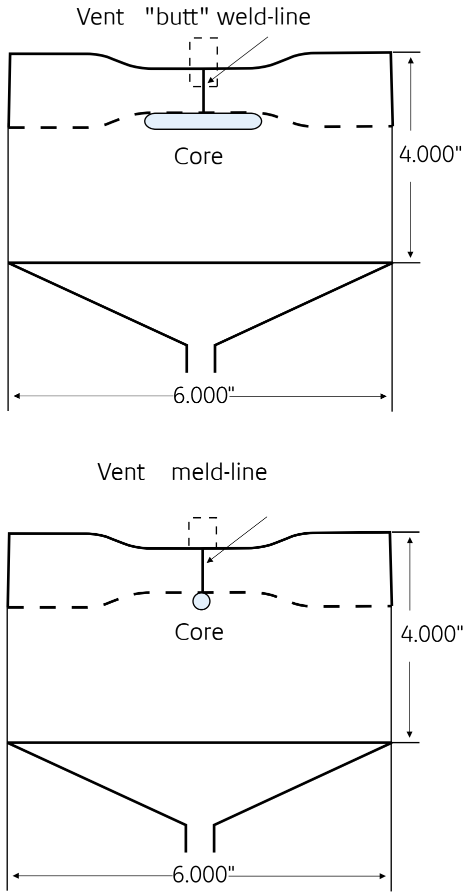
Weld-lines vs. meld-lines

Up to this point of the study our focus has been on "butt" weld-lines using an injection molded tensile specimen with flow fronts meeting head on. It has been suggested that a "meld" line formed where flow fronts rejoin while flowing parallel to each other offer greater strength than "butt" weld-lines. The purpose of this phase of the study was to compare "butt" weld-line strength with "meld" line strength in the reinforced composites.

For this phase of the study a 6" x 4" x 0.125" plaque mold was built using replaceable cores to allow formation of "butt" weld-lines or "meld" lines (see figures 3 and 4). Venting in this mold also included adequate relief to prevent compression of gasses in the weld area. In addition, this tool included an insert which would allow molding of specimens both with and without an overflow tab. It had also been suggested that an overflow tab can help to increase weld-line strength by moving the cold material out of the weld area thus increasing the efficiency of the knit.

A series of 25 materials containing various base resins, carbon and glass fiber reinforcement and polymer alloys were evaluated in this phase of the study. In determining the significance of the strength differences it was felt that at least a 10% improvement was necessary to consider moving gates/adding flow tabs to achieve enhanced strength. In reality much greater improvement would be necessary to consider these tooling changes due to the secondary operation of tab removal. In comparing the "butt" weld-line strength of a material to its meld-line strength little significant improvement was noted. Only one out of 25 materials Stat-Loy* A, an antistatic ABS alloy, had significantly higher meld-line strength. With a meld-line strength of 3300 psi and a "butt" weld-line strength of 2200 psi a 50% increase was noted by using the meld-line configuration of the mold. None of the other 24 materials tested exhibited any significant improvement in strength in a meld-line rather than a "butt" weld-line.

Figures 3 & 4



The addition of overflow tab in a “butt” weld-line configuration benefitted only 3 materials but improvements were more modest at 11–17% (table 10). When an overflow tab was added to the meld-line cavity, meld-line strength was enhanced in 4 materials which included the same 3 which saw increased “butt” weld strength, plus Lubriloy* compound RL, a wear resistant nylon 6/6 alloy (table 11). Strength enhancement was minimal with 10–15% improvement in meld-line strength at best. With only 3 of 25 materials showing significantly higher strength with an overflow tab in a “butt” weld-line and 4 of 25 with an overflow tab in a meld-line use of an overflow tab is unwarranted. The scope of materials which do show benefit from addition of an overflow tab is limited. Also the level of strength improvement in those materials which do benefit is not significant enough to warrant addition of a flow tab (or the secondary operation to remove it). In the end the most significant improvements in weld-line strength may be afforded by ensuring sufficient venting in the mold cavity as determined in the initial study.

Conclusions

- Weld-line strength of reinforced/filled composites is highly dependent on the inherent weld-line strength of the base resin.
- Adequate venting with relief at the weld-line is the simplest and most important design feature to maximize weld-line strength.
- The thermal conductivity of carbon fibers may increase the cooling rate of molten flow fronts and may require higher melt temperatures to maximize weld-line strength.
- Meld-lines do not have significantly higher strength than “butt” weld-lines.
- The use of overflow tabs may offer limited improvement in “butt” weld-line/meld-line strength in some composites but the improvement is not sufficient to consider addition of these features.

Table 10 Effect of overflow tab on “butt” weld-line strength of composites

Compound	Without tab psi	With tab psi	% increase
Stat-Loy* A	2,200	2,600	18
Thermocomp* UF-1009	13,400	14,900	11
Thermocomp RC-1006	11,000	13,000	18

Table 11 Effect of overflow tab on meld-line strength of composites

Compound	Without tab psi	With tab psi	% increase
Stat-Loy A	3,200	3,600	12
Thermocomp UF-1009	13,900	15,900	14
Thermocomp RC-1006	11,400	13,100	15
Lubriloy RL	4,000	4,600	15

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