AN EVALUATION OF POLYPHENYLSULFONE

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Prepared by R. J. Hishaw

Polyphenylsulfone, an engineering thermoplastic, was evaluated for potential applications where its superior properties would be of benefit. The evaluation included analysis and characterization, physical testing, parametric responses, and moldability. Analytical tools used included thermomechanical analysis, thermogravimetric analysis, differential scanning calorimetry, and standard ASTM physical tests. Statistical studies were used to determine dimensional responses to conditional changes in molding.

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SUMMARY

An engineering thermoplastic, polyphenylsulfone, was evaluated for potential applications where its temperature resistance and impact strength would be beneficial. This evaluation included polymeric analysis for characterization, physical testing, parametric response evaluation, and moldability.

The material was characterized by evaluation of carbon, hydrogen, nitrogen, oxygen, and sulfur content; solution studies; ash analysis; halogen tests; moisture analysis; gas permeation chromatography; differential scanning calorimetry; thermogravimetric analysis; thermomechanical analysis; and heat aging study. Major elemental contents and percentages were identified, and theoretical monomeric constituents were derived.

Physical testing was performed to provide comparative data and indications of effects of changes or variations in process conditions. Effects of major process variables on physical characteristics were determined. The effects of these variables on dimensional characteristics of shrinkage and warp also were evaluated. Testing of key physical characteristics on samples molded of recycled resin was also performed with favorable results.

Moldability evaluation was performed in conjunction with developmental efforts on current projects. Techniques for close-tolerance molding of common resins were evaluated for effectiveness.

Evaluation of this material is not complete. Remaining efforts include evaluating the effects of cyclic molding, the compatibility of high temperature mold heating and cooling, and the use of polyphenylsulfone in mechanisms.

DISCUSSION

SCOPE AND PURPOSE

Process techniques will be developed for production of parts from several high-performance thermoplastic materials. For the most part, these materials are new on the market, and little information is available.

Toughness properties, such as flexural and impact strength, and dimensional stability have made polycarbonate the dominant material for internal production application. Use of polyphenylsulfone, a thermoplastic resin advertising a balance of heat resistance and toughness properties, will allow expansion of applications into higher temperature ranges than those attainable with polycarbonate, while retaining those physical properties which are most desirable.

Weight concessions are negligible; polyphenylsulfone does not depend on heavy glass loading for its physical characteristics, as do many of its contemporaries.

This effort was the initial evaluation of this material; therefore, background information was generated through chemical analysis and characterization, physical testing, parametric evaluation, and molding endeavors.

ACTIVITY

Polyphenylsulfone is one of the newest engineering thermoplastics combining heat resistance characteristics with impact strength far greater than most of its contemporaries. The advertised properties of the material give an indication of its physical characteristics, as compared to similar materials (Table 1).

Polyphenylsulfone is supplied by the manufacturer as a transparent natural grade or as an opaque greyish-tan grade. The primary difference in grades is the addition of small amounts of pigment to eliminate transparency. Because of availability at the beginning of this evaluation, opaque grade was used primarily.

Polymeric Analysis and Characterization

Characterization activities revealed the primary elemental content of opaque grade polyphenylsulfone to be 71.61 percent carbon, 4.34 percent hydrogen, 15.46 percent oxygen, and 8.59 percent sulfur, proportionally. Primary elemental content of clear grade was 72.48 percent carbon, 4.33 percent hydrogen, 15.39 percent oxygen, and 7.8 percent sulfur.

Table 1. Physical Properties

Property	Materials*				
	1	2	3	4	5
Heat Deflection (°C at 1.82 MPa)	218.33	212.78	173.89	132.22	204.44
Izod Impact (N·m/m)	80.1	106.6	69.4	749.3	640.5
Tensile Strength (MPa)	147.55	119.28	70.33	62.05	71.7
Elongation (Percent)	3	5	50	110	60
Flexural Strength (MPa)	255.10	189.61	106.18	93.08	85.49
Specific Gravity (g/cm ³)	1.64	1.52	1.24	1.2	1.29

*The materials are:

1. Polyphenylene Sulfide,
2. Polybutylene Terephthalate,
3. Polysulfone,
4. Polycarbonate, and
5. Polyphenylsulfone.

Solution studies were not completed because a suitable solvent was not found. The material is soluble only partially in chloroform and tetrahydrofuran (THF). Dimethylformamide was the only room temperature solvent found.

Ash analysis revealed a 3.4 percent inorganic filler which was identified as primarily titanium dioxide (TiO₂). The material manufacturer used this additive because of clarity problems in

early production lots. It is not expected to be a permanent constituent of the material. Trace elements in the filler included 4000 parts per million (ppm) zinc, 15 ppm magnesium, 9 ppm silicone, 7 ppm iron, 6 ppm calcium, and 2 ppm aluminum. Total chlorine content was 0.155 percent, with a moisture level of 0.44 percent. These levels are considered of no significance.

Confirmative testing of clear grade polyphenylsulfone showed a considerable reduction in impurities with the exception of aluminum at 28 ppm. Notably, zinc (0.3 ppm), magnesium (6 ppm), silicone (2.5 ppm), and iron (0.3 ppm) showed sizable reductions. No calcium content was evident; however, chromium (2 ppm) and tin (0.3 ppm), not seen in the opaque grade, were apparent.

Total halogen (reported as chlorine) content of polyphenylsulfone was moderate and is probably representative of the amount of reactive endgroups left in the polymer. The most common method of polysulfone manufacture involves reacting a dihydroxy compound with a dichloro compound in the presence of a basic catalyst. This can be represented by the equation below.

The chlorine could also represent unremoved NaCl which is a reaction by-product.

Moisture analysis revealed relatively low levels of water. The presence of this water is probably harmless, because polysulfones are quite stable hydrolytically. CHNO and S analysis provided most of the data from which the structure was derived. This data was corrected for the 3.4 percent TiO₂ present in the polymer. As an aid in the structural identification of the polymer, an acetone extract of polyphenylsulfone was run by gas permeation chromatography, and fractions of each peak were collected. These fractions then were analyzed by infrared spectroscopy. The proposed structure which best fits CHNOS, infrared, and gas chromatography/ mass spectroscopy (GC/MS) data is as follows.

The theoretical composition of this structure is 71.98 percent C, 4.03 percent H, 8.01 percent S, and 15.98 percent O. No other theoretical structures correlated well with the actual CHN data.

Assuming the above structure to be correct, then the two monomers used to prepare the polymer are as shown.

and

Differential Scanning Calorimetry (DSC), used to determine sharp melting points or glass transitions, detected no phase changes at all. The polymer did soften and melt, but this occurred over a broad temperature range rather than at a discrete temperature. Thermomechanical analysis (TMA), which uses a loaded probe on top of the sample, detected no glass transition from -150 to 125°C. At about 210°C, the polymer expands rapidly; at 220°C, the polymer softens, and the probe penetrates the sample (Figure 1). This test was performed with a probe load of 310.26 kPa. The free standing polymer does not soften with this suddenness. Thermogravimetric analysis (TGA) was run in both air and nitrogen to determine the temperature at which degradation occurs (Figure 2). In nitrogen, the polymer is very stable to 455°C (15°C/minute heating rate), after which it rapidly decomposes to leave 45 percent by weight char. In air, the polymer is also stable to 455°C, but then decomposes to leave 3 percent residue of TiO₂.

Confirmative testing of clear grade showed virtually no differences in DSC, TMA, and infrared analysis. Likewise, dynamic shear moduli were identical. Some indication of slight stability improvement was seen in TGA.

A sample of the opaque grade polyphenylsulfone was placed in an air circulating oven at known temperatures in an effort to determine the polymer's long term stability in an oxidizing atmosphere. The polymer was quite stable to 220°C. At 250°C, the sample began to lose weight and to darken in color. After 35 days at 250°C, it had lost about 1.9 percent by weight, which is remarkably little. The initial loss of 0.3 to 0.4 percent after the first day appears to be the loss of processing oil used on the aluminum sample pans (Figure 3). Test results with clear grade showed no weight loss at 225°C after 30 days, and 1 percent weight loss after 57 days at 233°C.

Figure 1. Thermomechanical Analysis of Polyphenylsulfone

The proposed dihydroxybiphenol monomer is rather expensive and would seem to make this an unlikely candidate for commercial use. Other structures using a methylene or oxygen bridge between the two phenyl rings would make the monomer much cheaper, but these structures do not fit either CHN or GC/MS data. Unless other, more substantiating, evidence is found, the proposed structure still remains the most likely.

Figure 2. Thermogravimetric Analysis of Polyphenylsulfone

Figure 3. Long-Term Heat Aging of Polyphenylsulfone

Physical Testing and Parametric Response

Physical testing was performed to ASTM standards for evaluation of tensile strength, elongation, fiber stress, elastic modulus, notched Izod, and heat deflection. A statistical study was designed to evaluate five levels of melt temperature, mold temperature, and inject pressure. The above physical criteria were used as response as well as dimensional variations. Samples were produced in a six-cavity mold, producing one 101.6-mm-diameter by 3.175-mm-thick disc specimen, two 12.7- by 6.350- by 127-mm test bars, two 12.7- by 3.175- by 127-mm test bars, and one 3.17- by 215.9-mm tensile test bar. The study matrix and coded variable levels are given in Table 2.

Four parts from each cavity were retained for evaluation from each of the 16 lines. Twenty characteristics, listed below, were selected and reviewed as potential responses. Several of these characteristics (indicated by an asterisk) showed no detectable response or poor fit to the full quadratic models because of effects from unmonitored sources.

1. Thickness (6.350-mm impact bar);
2. Impact strength of 6.350-mm bar by notched Izod method (actual);*
3. Impact strength of 6.350-mm bar by notched Izod method (actual per linear centimeter);*
4. Impact strength of 6.350-mm bar (maximum per line);*
5. Thickness (3.175-mm impact bar);
6. Impact strength of 3.175-mm bar by notched Izod method (actual);*
7. Impact strength of 3.175-mm bar by notched Izod method (mean per linear centimeter);*
8. Impact strength of 3.175-mm bar by notched Izod method (maximum per line);*
9. Shrinkage (mean per centimeter, actual);
10. Shrinkage per centimeter parallel to flow (=);
11. Shrinkage per centimeter perpendicular to flow (|);
12. Shrinkage (| versus =);

Table 2. Study Matrix

Line	Matrix*		
	Melt Temperature, X_1 ($^{\circ}\text{C}$)	Injection Pressure, X_2 (MPa)	Mold Temperature, X_3 ($^{\circ}\text{C}$)
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1
9	-2	0	0
10	2	0	0
11	0	-2	0
12	0	2	0
13	0	0	-2
14	0	0	2
15	0	0	0
16	0	0	0

*Matrix codes are as follows.

Variable	Codes				
	-2	-1	0	1	2
X_1	365.56	376.67	387.78	398.89	410.00
X_2	56.88	67.22	77.57	87.91	98.25
X_3	137.78	148.88	160.00	171.11	182.22

13. Warp parallel to flow (=);
14. Warp perpendicular to flow (|);
15. Warp (| versus =);
16. Tensile strength;*
17. Tensile strength (maximum per line);
18. Elongation (percentage);*
19. Maximum fiber stress (flexural) at 5 percent strain; and
20. Flexural modulus.

Characteristics 1 and 5 used the measured thickness of impact bar specimens as response to parametric variations and showed thickness increases (reduction in shrink) with increases in melt temperature above the 0-level conditions. Interactions between the three variables was more evident on the 3.175-mm-thick samples than on the 6.35-mm-thick samples, indicating nonlinearity of cross-sectional shrinkage.

Injection pressure was nearly linear; thickness increased as incremental pressure increased. Maximums were outside the chosen range of pressures selected for this study. Mold temperature indicated a relative maximum on the thicker specimen at about $X_3 = -0.45$ (150°C).

Notched Izod impact tests (ASTM D256) were performed on both 3.175- and 6.350-mm specimens. Analytic evaluation of parametric effects are reflected in Characteristics 2, 3, 4, 6, 7, and 8. No single variable was seen to have significant effect on impact strength, indicating that acceptable fill and packing were attained throughout the study range. The thinner specimens indicated minor maximums for melt temperature at 384.4°C and mold temperature at 153.8°C.

Characteristic 9 was used to evaluate overall part shrinkage as the average of two dimensions taken at repeated positions from all submitted samples. These two positions were taken as measurements parallel to and perpendicular to material flow direction. Mean shrinkage by line was used to generate response curves. Injection pressure was the most responsive and significant independent variable; however, through interaction of all three variables, a sizable variation in mean shrinkage was attainable (0.197 to 0.487 percent). In no case was the shrinkage as great as expected. This may have been caused in part by the added filler in this lot of material, as alluded to earlier. Mean

shrinkage showed reduction with increases in all three variables independently. Apparent maximums were identified, but no finite minimums were seen.

Shrinkage parallel to flow (Characteristic 10) was also responsive to all variables, both independently and in interaction. Again, injection pressure was the most responsive independent variable. Similar responses were seen for Characteristic 11 (shrinkage perpendicular to flow), though to lesser overall percentage, as indicated by Characteristic 12 (difference in parallel and perpendicular shrinkage). This difference is minimized with melt and mold temperatures at the low end of the selected ranges of this study. This is apparently commensurate with maximizing mean shrinkage (Characteristic 9), which is not compatible with close-tolerance controls on molded parts. The mean difference in shrink was 0.124 percent, with the greatest shrink parallel to material flow. No variable or interacting variable set was identified that eliminated shrinkage differences.

Disc samples were used to evaluate warp. Warp is a loss of flatness attributed to internal stress or unequal shrinkage of opposing surfaces. Characteristics 13, 14, and 15 evaluate warp as a function of process variables. As with shrinkage, these characteristics are thought to be related to flow pattern and, therefore, are evaluated as parallel to material flow, as perpendicular to material flow, and as a dimensional difference between the two.

In parallel flow (Characteristic 13), the interaction between melt temperature and injection pressure showed the most significant response, yielding reduction in warp at upper levels of both variables. It was shown that these reductions could be offset by high levels of mold temperature. This finding indicates that this material is probably slow cooling, once boundary layers are solidified. Longer in-mold restraining may further reduce warp but at the expense of increased internal stress. Direct response was also seen to changes in melt temperature independently, resulting in better flatness at higher melt levels. No independent response was evident for injection pressure.

Warp characteristics were generally the same for melt temperature, but somewhat more responsive for other variables when measured perpendicular (Characteristic 14) to material flow. Again, interaction between melt temperature and injection pressure were most significant and beneficial; however, the improvements were offset by high mold temperature. Response to mold temperature increases were seen as steady increases in warped conditions. Worse conditions were seen with interaction of high mold temperatures with low injection pressures. Independent response to injection pressure seen in perpendicular flow was better at higher levels.

Warp patterns for melt temperature and mold temperature were so similar that no significant difference in warp (Characteristic 15) were seen for the two variables. That warp perpendicular to flow was responsive to injection pressure, while warp parallel to flow was not, created a direct response to injection pressure for this characteristic.

No highly significant terms were identified for average tensile strength (Characteristic 16). Variations observed did not indicate sensitivity to variables, either independently or in interaction. Fit of data to full quadratic was poor. Fit of maximum tensile strength by line (Characteristic 17) was much better. The data indicate that high levels of the three variables yield best strength with apparent maximums for injection pressure and mold temperature. No melt temperature maximum was noted.

Percent elongation data was erratic, varying from 15 to 100 percent. No definite trend with respect to process variation was noted. The average elongation of all samples tested was 39.8 percent.

Evaluation of maximum fiber stress (flexural strength) indicates melt temperature to be the most significant of the three major variables. Minimum strengths were seen at low levels of all variables, both independently and in interaction. No maximums were identified within the range of this study. Indications are that the highest attainable levels of the three variables, without physical degradation, will yield best flexural properties.

Flexural modulus (stiffness in flexure) showed similar responses to melt temperature increases, which again was the most significant variable and was most beneficial at higher levels. Direct improvement was also evident as injection pressure was raised. No direct effects of mold temperature were seen; however, higher levels are favored in interaction with high melt temperature.

The pertinent values from physical testing, showing maximum, minimum, and mean values for each characteristic are given in Table 3. In addition, comparative test results of unfilled clear grade are shown. It should be noted that clear grade polyphenylsulfone tested below the opaque grade mean values for both Izod impact and tensile strength. Flexural strength and flexural modulus of clear grade tested below study minimums for the filled grade. The clear grade was superior in elongation, which indicates better flexibility. Heat deflection occurred at above 195°C for both grades; the opaque grade deflection was slightly higher.

Recycled Resin

The use of recycled material is recognized as a major economic advantage in selection of thermoplastic materials over thermosets or metals.

Table 3. Physical Test Values, Opaque Grade

Characteristic*	Unit	Values			Standard Deviation**	Averages Clear Grade	Averages Opaque Grade
		Maximum	Minimum	Mean			
1	mm	6.4465	6.3246	6.3805	0.030		
5	mm	3.3604	3.2131	3.2664	0.046		
7	N•m/m	764.92	435.03	628.80	87.35	553.54	689.12
8	N•m/m	864.73	656.02	724.13	44.36		
9	mm	0.124	0.050	0.081	0.020		
10	mm	0.137	0.069	0.098	0.018		
11	mm	0.112	0.031	0.066	0.022		
12	mm	0.045	0.022	0.031	0.007		
13	mm	0.229	0	0.125	0.083		
14	mm	0.191	0	0.107	0.069		
15	mm	0.102	0	0.018	0.041		
16	MPa	79.46	68.05	77.00	1.96	72.42	71.70
17	MPa	79.98	77.22	78.38	1.14		
18	Percent	55.0	22.0	39.8	10.3	64	19
19	MPa	98.60	93.29	95.70	1.47	91.01	91.70
20	MPa	2594.2	2373.5	2420.6	53.08	2213.2	2351.1

*Description of characteristics given in text on page 12. Values are line averages unless otherwise indicated.

**Calculated for 16 data points in each characteristic, representing line average for each sample set. As conditions were varied by study design, these values are somewhat inflated and are representative of ranges expected with an unstable process.

Production at Bendix has not consisted of sufficient volumes of any single material to cause serious concerns with the use of reground sprues, runners, purgings, or scrap. In addition, most thermoplastic materials are relatively inexpensive, and physical and visual quality are known to be compromised by recycling. Quality problems are normally minimized by blending some percentage (normally 25 to 50 percent) of reground material with previously unmelted (virgin) resin.

The expense and the currently unstable supply required that the potential of polyphenylsulfone for recycling be evaluated. This evaluation was performed as an ovetest in which 100 percent recycled material was used to produce samples for physical testing. It should be noted, however, that obviously degraded scrap and contaminated purging were discarded prior to regrinding.

Table 3 shows the average values of key physical tests performed on samples from recycled resin. Comparison to data generated from virgin resin revealed that elongation was affected most significantly, dropping 52.5 percent below mean tested values for virgin resin. Flexural strength and flexural modulus also were affected adversely, but not as significantly. Heat deflection testing indicated no effect. Slight decreases were seen in Izod impact and tensile strength.

Molding Evaluation

In development of matrix assemblies, early work was done with phenolic and polycarbonate materials. These materials did not offer the balance of rigidity, machinability, crack resistance, dimensional stability, bondability, and heat resistance that was desired. As development progressed, desired characteristics, with the exception of heat resistance, were obtained with polysulfone, which lead to an interest in polyphenylsulfone.

The mold used with polycarbonate and polysulfone was used for initial developmental work with polyphenylsulfone. The mold consisted of modified inserts in a production base, and four-zone mold temperature control was established at negligible cost.

Two visual problems were encountered when the first parts were molded: degradation around the part periphery (edge burn) and fine surface lines resembling peeling that projected from the center gate radially toward the part edge (splay marks).

Generally related to fill rate, edge burn occurs when the cavity is filled faster than air can escape and with high pressure. Edge burn is eliminated either by venting the mold to provide air escape or by reducing the fill rate. Because of the part geometry, venting would not be foolproof, and slow fill rates are not recommended by the material manufacturer. Therefore, a combination

of primary and secondary injection pressures had to be established, using a rapid fill rate for approximately 85 percent of fill and a reduced rate and pressure for the final 15 percent of fill. This technique is similar to those used for polybutylene terephthalate. Ideally, the changeover from high to low inject should be position controlled; but, because the molding equipment used is not so equipped, the changeover is controlled by timers. Thus, percentages will vary with viscosity variation and will add another variable to the process. The effect of such variation on dimensional repeatability has not been determined.

The splay marks are related to moisture levels in the resin and reflect the stringent drying requirements of the material. Hopper settings of 135°C for 5 hours with a controlled dew point of -6.66°C appear insufficient. After 5 hours at a 148.8°C setting, the marks were reduced but not eliminated. Higher hopper temperature settings may be needed to establish a material temperature of 148.8°C for adequate drying. This need will be investigated.

A constant temperature process, using the following conditions, was established:

Molding surface temperature of 176.67°C;

Melt temperature of 393.33°C;

Maximum shot speed for 2.2 s at 137.89 MPa; and

Injection hold at 96.53 MPa.

The parts produced are geometrically chordal in cross section with a circular periphery, allowing free state contour checks with radial sweep gaging. The similarity of these moldings to former polycarbonate parts provided for convenient dimensional analysis with set-up changes to existing gages and for comparison of responses to those seen in earlier development efforts.

The quantity of material available for this effort was limited; therefore, several rapid mold temperature changes were made to determine material dimensional response characteristics to mold temperature variation and punch/cavity temperature differences (Δt). Two levels of melt temperature were used.

Very slight changes were seen in part thickness as a result of changes to melt or mold temperature. A melt temperature increase from 385°C to 399°C resulted in only 0.0381 mm (about 0.79 percent) increase in maximum thickness. Mold temperature increases from 176.67°C to 201.6°C resulted in a maximum thickness increase of 0.0761 mm. Runout in thickness in all cases was 0.0761 mm or less and decreasing with distance from the gate, which may relate to the fill mode discussed earlier.

Contour responses to changes in mold temperature are not attained as readily as those seen with polycarbonate moldings in earlier constant mold temperature efforts. This resistance to dimensional change is caused partly by the more restrictive geometrical characteristics of a full chordal section, as compared to the pentagonal shapes on which most previous experience is based. No appreciable change was seen until mold surface temperatures approaching 204.5°C were used. These temperature levels were predictable, because they approach the estimated minor transition point of 215.5°C. The improvement in total indicator readings noted at this point represents a general opening of contour approaching a desired radius but is not indicative of improvement in radial characteristics. Parts at all levels indicated excessively warped surfaces, accounting for about 0.127 mm surface deviation. These characteristics were not significantly affected by controlled opposing-surface temperature differences of up to 27.7°C. No contour responses to changes in melt temperature were detected, indicating that a more radical change in melt temperature would be necessary to affect part dimensions.

Increases in melt and mold temperature were beneficial in aiding visual problems related to flow around barriers and restrictions. Parts were produced containing threaded inserts, locating slots, and through holes without adverse visual consequences.

Parts were produced of 50 percent recycled resin without significant change to processing conditions. Visual appearance and dimensional characteristics were unaffected.

To evaluate compatibility with thin-walled molding, attempts were made to mold a protective cover configuration. The flow demands of this molding are severe; approximately 140 mm of flow are required through a 1.0-mm cross section in a 127-mm cylindrical shell configuration. This configuration had previously been processed in unfilled grades of polycarbonate, polysulfone, and transparent polyamide. Complete fills were obtained with these materials using standard molding practices. Because clarity is a desired characteristic of this product type, clear grade was used for this activity.

Standard molding techniques were not adequate. Constant mold temperature up to 205°C with full taxing of injection pressure (206.8 MPa) was insufficient for obtaining fill at a melt level of 400°C. A cyclic mold profile was introduced in which the mold temperature was raised to 249°C at inject and reduced to 177°C at part removal. Full parts were produced by this technique; however, severe degradation problems were encountered as barrel residence time of the material became extensive. This excessive cycle time (15 minutes) caused more purging and material waste. An effective process for this configuration may require lower melt temperature (385°C) with higher injection pressure (276 MPa). Cyclic mold profile with temperature as high as 315°C may be necessary.

ACCOMPLISHMENTS

Polyphenylsulfone was found to have good flow properties and appeared to be highly processable. However, the elevated melt temperature makes the material incompatible with some injection molding equipment. For products with loose tolerance requirements and ingenious flow patterns, common molding considerations should yield adequate results. The mold should be well vented. Particular attention must be paid to drying. Close-tolerance moldings of large assymmetric or unbalanced parts will be more difficult because of anisotropic shrinkage revealed during physical testing. Center gating should be the predominant method used. Thin-wall moldings with extensive flow requirements cannot be produced on conventional equipment. An injection pressure of 241 MPa and cyclic mold profiles in excess of 300°C are necessary for thin-wall moldings.

In most cases the material tested above its advertised values. Sensitivity to contamination and a tendency toward rapid degradation at elevated melt levels probably is responsible for the wide ranges of values evident for some characteristics. This incompatibility with excessive residence time is an adverse consequence of the typically long cycles used at Bendix. Long cooling times and hot molding techniques, which are unique to Bendix production, will have to be abandoned when optimization of physical properties is desirable. These techniques should be used only when dimensional concerns outweigh physical ones.

Testing of moldings from recycled resin were encouraging. It is suggested that usage up to 30 percent be considered for production activity and be so specified where applicable.

The theoretical structure derived from characterization activity indicates the use of a dihydroxybiphenol monomer. Production of this monomer is expensive; therefore, this material is unlikely to receive wide commercial acceptance. A recent price restructuring and limited quantity commitment from the supplier substantiate this conclusion. No firm design activities should be instituted until supply conditions stabilize.

FUTURE WORK

Efforts with polyphenylsulfone in development will continue. Efforts will be limited to comparative testing of unpigmented resin, effects of the use of regrind, effects of cyclic molding, and applications in mechanisms.

Aromatic copolyester, polyamide-imide, and other high performance polymers advertising clarity, lubricity, and wear resistance characteristics also will be evaluated.

The final phase will deal with compatibility of these new materials with high temperature mold heating and cooling techniques.

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