WELDLINE INTEGRITY IN FOAMED POLYPHENYLENE ETHER ALLOYS

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INTRODUCTION

The molding conditions under which a thermoplastic material is processed has a major influence on its properties and consequently final part reliability. Studies covering thermoplastic properties as they relate to molding history have contributed to a good base of processing information. This information can be used to identify the best molding conditions for a given part.

The exact relationship of any plastic material performance to molding conditions varies with each material, i.e., each material has its own identity.

Structural foams based on polyphenylene ether alloys are studied in this paper. The influence of processing conditions will be traced for the alloy as a homogeneous solid and as a structural foam. Weldline integrity as a function of processing history will also be explored.

EXPERIMENTAL

Test specimens were molded in an ASTM tensile bar mold (see Figure 1). Tensile test values were taken directly from the tensile bar. Unnotched Izod impact strength was determined from specimens cut from the center of the bar.

The tensile bar mold is designed with gates at both ends of the sample. When material flows through only one gate, it produces a pattern of material flowing from one end of the bar to the other. This test specimen is used to represent material flow under standard flow conditions and with no weldline.

When both gates of the tensile bar are opened the melt fronts of the material advancing from both ends collide at the center span of the tensile bar and produce a weldline. The location of the weldline in the tensile bar allows the specimen to be used in both tensile strength and unnotched Izod impact strength tests.

TYPES OF SAMPLES

The focus of this study is on a polyphenylene either alloy structural foam, Prevex® BJA polymer. The purpose of the evaluation is to provide information on material performance in areas of typical material flow and part areas containing weldlines. Two different chemical blowing agents, azodicarbonamide and sodium bicarbonate, were used to achieve the foam cell structure.

To provide insight into the effect of the foam process on material properties the same molding conditions were imposed on the material in a solid form. Therefore, solid samples with and without weldlines were tested to compare to the foamed results.

MOLDING CONDITIONS

The molding conditions selected for the study were stock temperatures of 520°F and 600°F and mold temperatures of 100°F and 180°F. Fill rates for the tensile bar specimen were 0.25″/sec. and 1.0″/sec. (actual rate of screw travel in the molding machine, not melt front velocity).

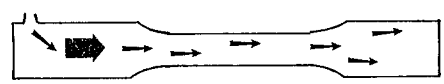
The molding conditions were arranged in a 2^3 factorial design. (See Figure II).

TESTS APPLIED TO SAMPLES

The physical property tests applied to the molded specimens were chosen to provide information on material performance as it is affected by molding conditions. The properties measured were tensile strength, unnotched Izod impact strength, oven shrinkage (an indication of total orientation) and density.

FIG I

SINGLE GATE - STANDARD FLOW



DOUBLE GATE - WELDLINE FLOW

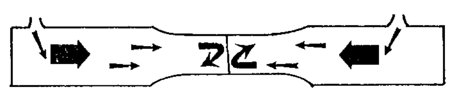
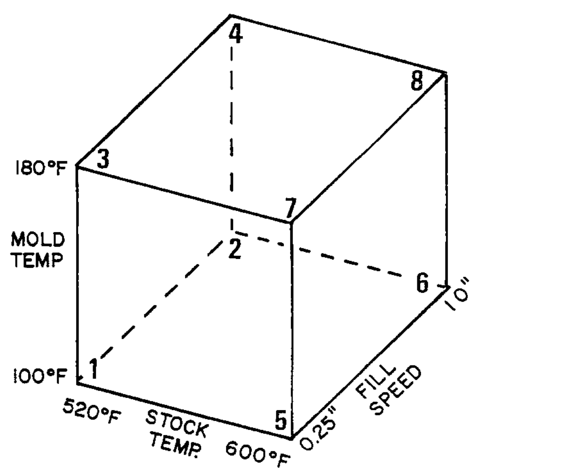


FIG II

2^3 FACTORIAL STUDY OF THE INFLUENCE OF MOLDING CONDITIONS ON WELDLINE STRENGTH



Presented at the Twelfth Annual Structural Foam Conference and Parts Competition, The Society of the Plastics Industry, Inc., May 7-9, 1984, San Francisco, CA.

FIG IIIA

FIG IIIB

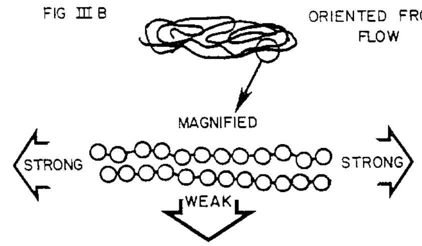
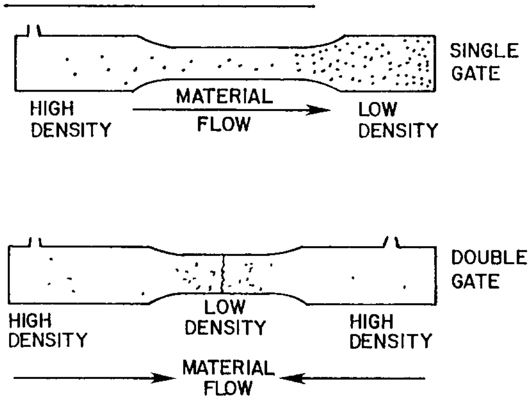


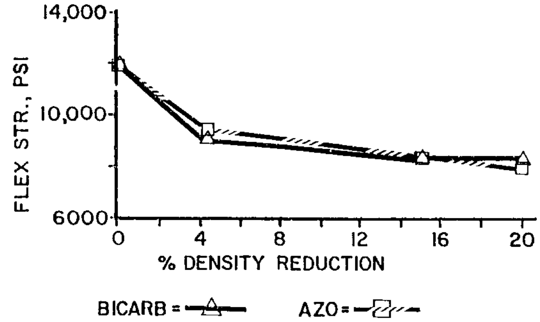
FIG IV

SAMPLE DENSITY GRADIENT



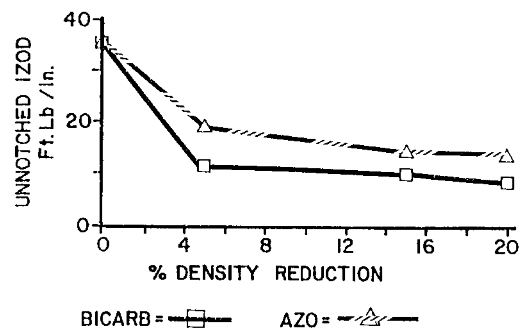
GRAPH I

INFLUENCE OF DENSITY ON FLEX STRENGTH



GRAPH II

INFLUENCE OF DENSITY ON IMPACT STRENGTH



Tensile properties were developed at a low strain rate, 0.02"/min. These properties, whether on a typical material cross-section or one containing a weldline, indicate material ability to sustain long term loads. These data are also applicable to periodic but predictable loading, e.g., using a CRT housing as a storage area.

Unnotched Izod impact strength provides a reasonable indication of material toughness under high speed loading, e.g., abuse during assembly or shipping.

Oven shrinkage, as an indication of total orientation, provides some measure of dimensional stability under load or exposure to high temperatures.

Density is simply a measure of the degree of foaming and effects part weight, stiffness and toughness.

DISCUSSION

The data on solid Prevex® BJA polymer are provided primarily for background information. Information on the sensitivity of solid material properties both in a typical material cross-section and a cross-section containing a weldline have been covered in several technical papers (1, 2). Generally, molding conditions that increase orientation increase the property values of tensile bar specimens without a weldline. When there is a weldline in the test sample, conditions that increase the tendency to orient the flow of polymer decrease the strength values of the weldline.

The low strength of the weldline due to orientation is illustrated in Figure III A & B. Weldline strength in the weak direction is dependent upon Van der Waals forces rather than chemical bond strength.

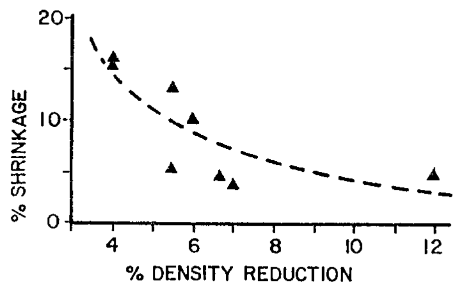
The discussion of structural foam properties involve several factors beyond the solid material base data. Density is one consideration. Another influence is the chemical blowing agent.

Part density reduction is based on a comparison of the weight of a solid part and one that has a cell structure. This technique provides only general information. Even a simple tensile bar has a significant gradient in density from the gate to the far end of the bar. (See Figure IV.) Consequently part of the data includes density information in the area of test bar failure. These data contribute to understanding the differences in values for different molding conditions.

When molding conditions are fixed and density of the foamed test specimen is varied the results form a predictable pattern which show that the lower the density the lower the strength property. This simple relationship is demonstrated by Graphs I and II. The flexural strength values for both the azodicarbonamide and sodium bicarbonate blown samples are the same within test error. The impact strength values have a similar profile for both blowing agents. The azo blown samples have a higher value because of a finer, more uniformly distributed cell structure. If the eight molding conditions changed only the density of the material, weldline test values would be easily related to a particular molding condition. However, density and orientation are interrated as shown in Graphs III and IV. These graphs show the relationship between density and orientation. The graphs, covering both weldline and non-weldline samples have the same pattern. The relationship is that lower density results in lower orientation which would be expected since material flow in low density areas responds in part to gas pressure. For solid parts the only force to move material in the melt state is hydraulic pressure. The pressure in a solid part is maximized in the gate area and consequently all material movement is away from the gate. For structural foam material the final filling is accomplished by gas pressure which is equal in all directions. This pressure is low compared to the melt pressure used to fill a solid part. The

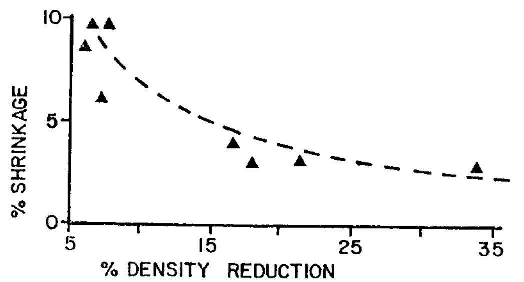
GRAPH III

EFFECT OF DENSITY ON ORIENTATION FOR STANDARD SAMPLES - AZO BLOWING AGENT



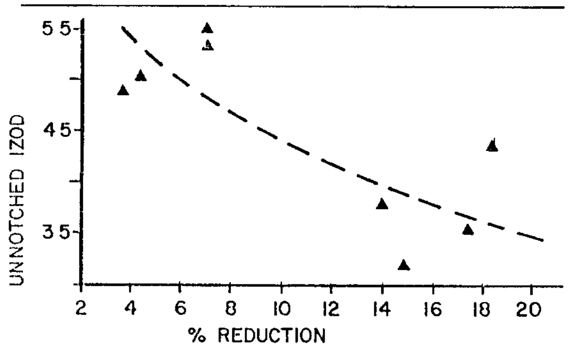
GRAPH IV

EFFECT OF DENSITY ON ORIENTATION WITH WELDLINE - AZO BLOWING AGENT



GRAPH V

INFLUENCE OF DENSITY ON IZOD STRENGTH OF STANDARD FLOW IN STRUCTURAL FOAM



SEE NOTES FOR TABLE IV

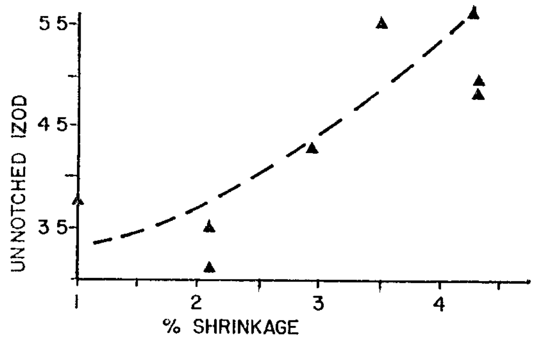
three dimensional low pressure of the expanding gas means that it cannot force order on the polymer melt. Therefore the force that it does apply does not have a strong directional component.

The sodium bicarbonate blown structural foam test samples shows a relationship between density and unnotched impact strength. For samples without weldline, the lower the density the lower the impact strength of the sample. (See Graph V.) The relationship between impact strength and orientation is that orientation favors impact strength development in samples with standard flow. This observation for foam is consistent with that of solid samples, i.e., it is more difficult to break a sample across the direction of material flow than with the flow of material. (See Graph VI.)

In the examination of properties for weldline performance the relationship between density and strength remains. The greater the density the greater the strength. (See Graph VII.) For orientation effects, the strength relationship is the opposite in samples containing a weldline as it is for samples

GRAPH VI

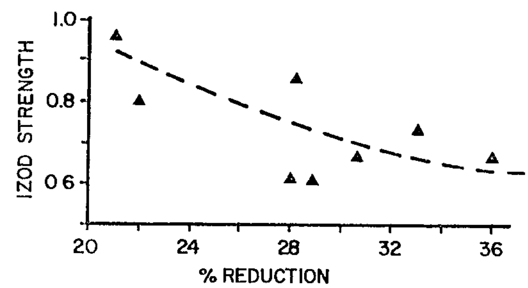
INFLUENCE OF ORIENTATION ON IZOD STRENGTH OF STANDARD FLOW IN STRUCTURAL FOAM



SEE NOTES FOR TABLE IV

GRAPH VII

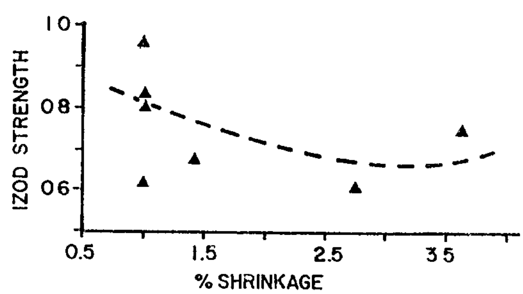
INFLUENCE OF DENSITY ON UNNOTCHED IZOD STRENGTH IN STRUCTURAL FOAM WITH WELDLINE



SEE NOTES FOR TABLE IV

GRAPH VIII

INFLUENCE OF ORIENTATION ON UNNOTCHED IZOD STRENGTH ON STRUCTURAL FOAM WITH WELDLINE



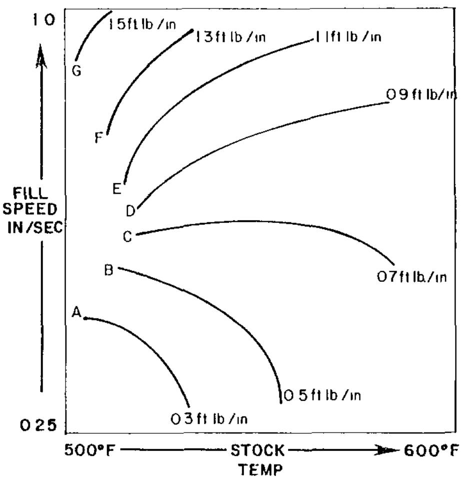
SEE NOTES FOR TABLE IV

without weldline. In samples containing a weldline high orientation yields low strength. (See Graph VIII.)

Graphs are presented to illustrate different relationships between factors influencing weldine strength. These graphs often have the values occurring in clusters, e.g., Graph V. The clusters of data points indicate the interaction between molding conditions and weldline performance that is dominated by a simple molding parameter. The fact that one variable in the factorial design has the most influence is more clearly shown in the cube diagrams (see Diagram I to VI). It is apparent that stock temperature is the major influence in the tensile elongation of sodium bicarbonate blown samples containing weldlines. The 2 to 3rd factorial design can also be used for contour plots of the data (see Graphs IX and X). The contour plot is helpful to track the influence of different molding conditions on product performance. The contour

GRAPH IX

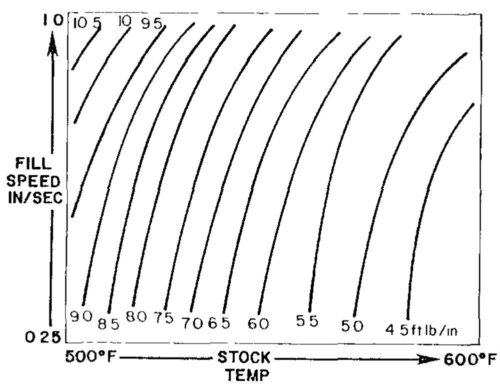
CONTOUR PLOT - STRUCTURAL FOAM
UNNOTCHED IZOD IMPACT STRENGTH



SEE NOTES FOR TABLE IV

GRAPH X

UNNOTCHED IZOD IMPACT STRENGTH
STANDARD FLOW, STRUCTURAL FOAM



SEE NOTES FOR TABLE IV
MOLD TEMPERATURE AT 100°F

DIAGRAM I

WELDLINE FLOW
STRUCTURAL FOAM
SODIUM BICARBONATE BLOWING AGENT
IMPACT STRENGTH

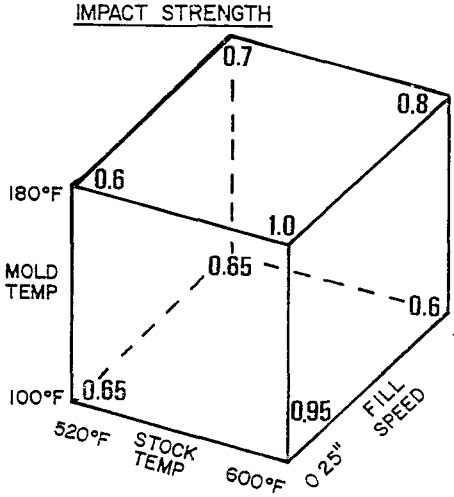


DIAGRAM II

WELDLINE FLOW
STRUCTURAL FOAM
SODIUM BICARBONATE BLOWING AGENT
TENSILE STRENGTH

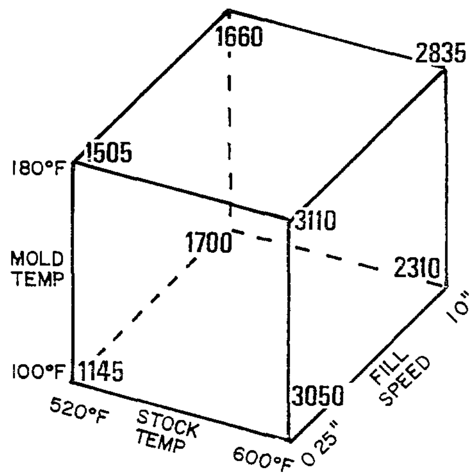
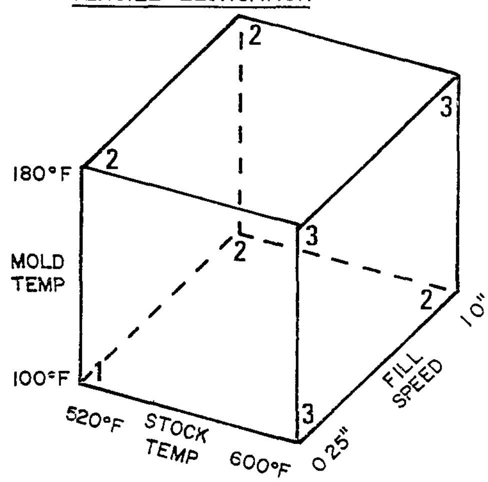


DIAGRAM III

WELDLINE FLOW
STRUCTURAL FOAM
SODIUM BICARBONATE BLOWING AGENT
TENSILE ELONGATION



plot is particularly useful when the relationship between a property and molding condition is complex as illustrated in Graph IX. The more straightforward relationships between molding conditions and properties can be identified without such a plot (see Graph X). Graph X indicates that the predominant influence on unnotched impact strength is stock temperature, information that could be determined from the cube diagram.

The data are presented to illustrate relationships between properties of a structural foam part and the molding conditions by which the part was produced. The particular value of tensile bar data is often questioned as to meaning in terms of commercial parts. Certainly in an industry that is producing shot sizes of over 100 pounds this is a legitimate concern. The value of small samples is the ability to test multiple samples and identify cause and effect relationships. The data on the test samples indicate that azodicarbonamide blown structural foam parts have the capacity to reach higher levels of performance than sodium bicarbonate blown parts. On the other hand sodium bicarbonate blown samples do not fall to as low a value under unfavorable molding conditions.

DIAGRAM IV

STANDARD FLOW
STRUCTURAL FOAM
SODIUM BICARBONATE BLOWING AGENT
TENSILE STRENGTH

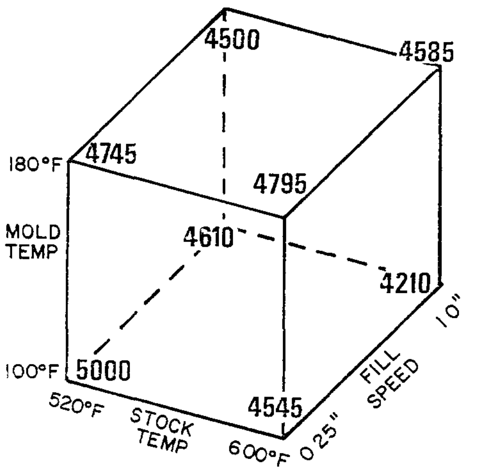


DIAGRAM V

STANDARD FLOW
STRUCTURAL FOAM
SODIUM BICARBONATE BLOWING AGENT
UNNOTCHED IZOD

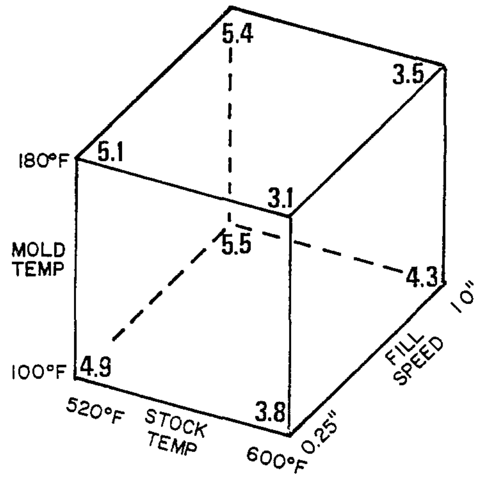


DIAGRAM VI

STANDARD FLOW
STRUCTURAL FOAM
SODIUM BICARBONATE BLOWING AGENT
TENSILE ELONGATION

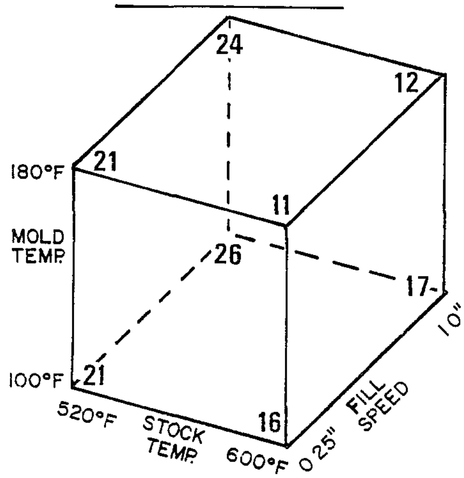


TABLE I

SET CODE FOR MOLDING CONDITIONS
FOR WELDLINE STUDY

SET NUMBER	STOCK TEMPERATURE	MOLD TEMPERATURE	FILL SPEED
1	520°F	100°F	0.25"/SEC
2	520°F	100°F	1.00"/SEC.
3	520°F	180°F	0.25"/SEC
4	520°F	180°F	1.00"/SEC
5	600°F	100°F	0.25"/SEC
6	600°F	100°F	1.00"/SEC
7	600°F	180°F	0.25"/SEC
8	600°F	180°F	1.00"/SEC

TABLE II

POLYPHENYLENE ETHER COPOLYMER ALLOY PROPERTIES
SOLID WITH STANDARD FLOW

SET NO	% SHRINKAGE	TENSILE STRENGTH	TENSILE ELONG.	UNNOTCHED IZOD
1	21.1	5205 PSI	57 %	43.4 ft lb/in
2	16.8	5025	65	54.4
3	18.2	5130	59	11.8
4	14.6	5035	54	14.0
5	10.2	5455	28	24.9
6	8.7	5520	54	35.1
7	10.9	5985	47	17.6
8	10.1	5715	46	28.2

TABLE III

POLYPHENYLENE ETHER COPOLYMER ALLOY PROPERTIES WITH WELDLINE

SET NO.	% SHRINKAGE	TENSILE STRENGTH	ELONG.	UNNOTCHED IZOD
1	15 3	4625 PSI	14 %	2.8 ft lb/in
2	13.1	4695	10	2.8
3	11 6	4665	17	2 7
4	9.5	4585	11	2 4
5	6 5	5060	19	3.7
6	5 1	5005	15	3 0
7	5.8	5470	13	3.4
8	5.1	5115	10	4.3

TABLE IV

PROPERTIES OF BICARBONATE BLOWN STRUCTURAL FOAM, WITH STANDARD FLOW

SET NO	% SHRINKAGE	% REDUCTION	TENSILE STRENGTH	ELONG	UNNOTCHED IZOD
1	4.3	3 3	5000 PSI	21 %	4 9 ft lb/in
2	4 3	5.9	4610	26	5 5
3	4.3	4.0	4745	21	5 0
4	3.6	5 9	4500	24	5.4
5	1.0	13.9	4545	16	3.8
6	2.9	18 6	4210	17	4.3
7	2.1	14 6	4795	11	3.15
8	2 1	17.6	4585	12	3 5

ALL SAMPLES 15% REDUCTION
IZOD IMPACT STRENGTH VALUES AVERAGE OF SIX SAMPLES
TENSILE VALUES AVERAGE OF THREE SAMPLES

TABLE V

PROPERTIES OF BICARBONATE BLOWN STRUCTURAL FOAM WITH WELDLINE

SET NO.	TENSILE STRENGTH	ELONG.	UNNOTCHED IZOD	% REDUCTION	% SHRINKAGE
1	1145 PSI	1 %	0.65 ft lb/in	36.0	1.4
2	1700	2	0.65	30.6	1.4
3	1505	2	0.60	28.8	2.8
4	1660	2	0 70	33.4	3.6
5	3050	3	0.95	20.7	1.0
6	2310	2	0 60	27.8	1 0
7	3110	3	0.85	20.0	1.0
8	2835	3	0.80	22.0	1.0

SEE NOTES FOR TABLE IV

An examination of high and low strength weldlines in tensile bars provides some insight as to how to examine weldlines in parts. One of the results of the test series is that low density areas generally have low mechanical strength. Critical areas of a structural foam part can be examined for density. The studies with the tensile bars in this report show large changes in density gradient. These changes in density occur in samples that have a fixed overall density reduction target. The maximum material flow in these samples is 8.5 inches for the standard flow bars, 4.25 inches for weldline samples. In a complex part weighing 100 pounds it is not difficult to predict large density changes in different part areas with changes in molding conditions even when the overall part weight remains the same.

TABLE VI

PROPERTIES OF AZO BLOWN STRUCTURAL FOAM WITH STANDARD FLOW

SET NO	% SHRINKAGE	% REDUCTION	TENSILE STRENGTH	ELONG.	UNNOTCHED IZOD
1	15.3	3.9	5935 PSI	22 %	10.8 ft lb/in
2	12.4	5.4	5675	29	10 9
3	16.0	3.9	5435	32	7.7
4	9.5	5.9	4910	43	9.3
5	5.1	5.4	5355	16	3 9
6	3.6	7 1	5155	20	5.1
7	4.3	6.8	5375	20	4.0
8	3.6	11.8	5130	26	6.0

SEE NOTES FOR TABLE IV

TABLE VII

PROPERTIES OF AZO BLOWN STRUCTURAL FOAM WITH WELDLINE

SET NO	% SHRINKAGE	% REDUCTION	TENSILE STRENGTH	ELONG	UNNOTCHED IZOD
1	9.5	6.5	660 PSI	1 %	0.3 ft lb/in
2	8.7	6.0	4960	10	1.5
3	9.5	7.3	3620	5	0 3
4	6.5	6.7	4875	11	2 4
5	2.1	32.6	2250	2	0 5
6	2 9	16.7	2070	3	0 7
7	2.1	21 4	2035	2	0.7
8	2.1	17.9	3195	3	0.7

SEE NOTES FOR TABLE IV

The other important factor highlighted by the study of tensile bars is orientation. The influence is covered by photographs using both solid and foam samples. Low strength samples are characterized by the level of sample shrinkage when heated to the sample reversion temperature. This temperature for Prevex® BJA polymer is 150°C. When the shrinkage of the weldline area is high the orientation in the weldline area is high. High orientation results in low weldline strength. See photograph sets 1 and 2.

Tabulated data are included on the structure of the factorial design and test results for both solid and structural foam samples. Both the sodium bicarbonate and azodicarbonamide blowing agents are included.

CONCLUSIONS

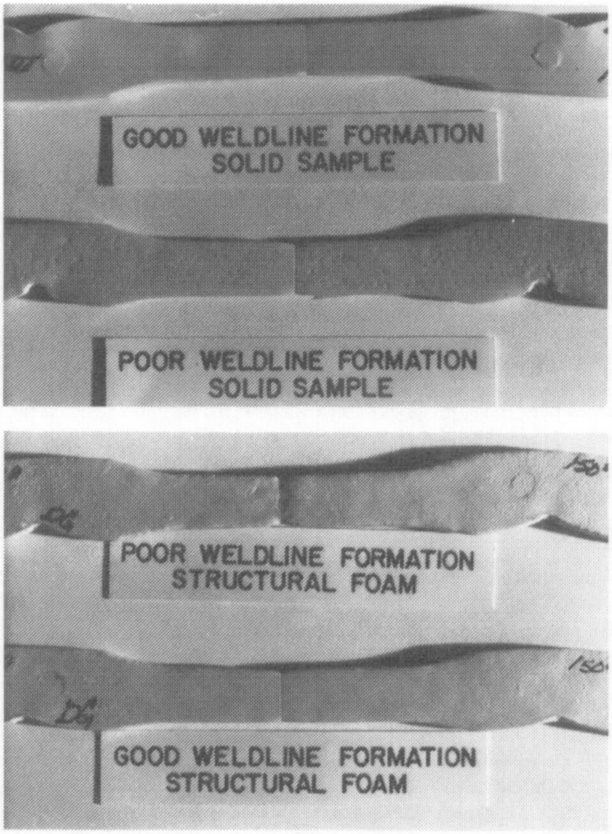
Within a structural foam part of fixed weight reduction, changes in molding conditions can cause major changes in part performance, e.g., impact strength can change by factor of 8.

The choice of blowing agent has a significant influence on the relationship between part performance and molding conditions, e.g., the azodicarbonamide produced both the highest and lowest strengths in the test series.

High density at the weldline area (or break area of a standard flow sample) generally increases the strength of that area.

Molding conditions that result in high material orientation in standard flow specimens generally increase the strength values of tensile samples.

Molding conditions that result in high orientation are unfavorable to high strength development in samples containing a weldline.



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1. "Structure and Property of Weldlines in Injection Molded Thermoplastics," S. C. Malgnanera, SPE ANTEC Papers, 1981.

2. "Weldline Fracture in Molded Parts," E. M. Hagerman, Plastics Engineering, October, 1973.

BIOGRAPHY

Mr. Gordon Brewer received his B.S. in Chemical Engineering from the Illinois Institute of Technology in 1960. His professional and technical experience includes 16 years with Borg Warner Chemicals. During that time he has worked primarily in the Materials Engineering group and concluded his service with the group as Section Manager.

Mr. Brewer is now a Staff Scientist—Materials and is responsible for the appraisal of new materials and technologies.