Urethane Foam Process Improvements

Kansas City Division

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URETHANE FOAM PROCESS IMPROVEMENTS

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Final Report
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ABSTRACT

A study was completed to evaluate the foam molding process for environmental and technical improvements. The investigation led to a replacement for chlorinated solvent usage, a potential permanent mold release coating, improved tooling design, and shrinkage characterization of foams filled with varying levels of aluminum oxide.

SUMMARY

Environmental concerns associated with processes have been on the increase in recent years. On September 1, 1985, guidelines were set forth under the Resource Conservation and Recovery Act (RCRA) requiring generators of hazardous waste to "have a program in place to reduce the volume and toxicity of waste generated to the extent that is economically practical." In response to these requirements, a study was initiated to evaluate non-CFC (chloro-fluorocarbon), non-CHC (chlorinated hydrocarbon) replacement solvents for foam machine flush cycles. In addition, process wastes could be reduced through reductions in scrap and improved characterization. The filled foam process was the least characterized foam process and thus a likely candidate for increased attention.

The purpose of this study was to evaluate the foam molding process for environmental and technical improvements. Specifically, it was to determine a nonhazardous replacement solvent for the flushing of foam mixing heads and to characterize the aluminum oxide-filled foam process.

The investigation of mold release coatings included the evaluation of a permanent coating called "NiFluor." Several molds were coated with this material and produced mixed results. In applications where molded product features had smooth contours, the coating worked well as the only source of mold release. Typical foam products, however, have irregular shapes and surfaces which result in a high degree of friction. For these applications the permanent coating was of little value as it had to be supplemented with a carnuba wax mold release. The coating did appear to be durable, although no long-term molding cycles were performed as part of this study.

A mold design study was also conducted to improve inner-to-outer diameter concentricity in thin-walled molded product. The mold improvement was marginally successful at improving concentricity.

An extensive study of the shrinkage characteristics of aluminum oxide-filled foam at varying processing conditions was completed. It was found that the filled foam shrinkage follows the general trend of non-filled foams in the fact that higher cure temperatures led to the larger shrinkage rates. Overall, the shrinkage amount of the higher loaded material was less than the lower loaded material, which was less than non-loaded foam.

It is recommended to replace the chlorinated solvent with DBE-2 (incorporated in CY90) and to utilize the NiFluor coating as a mold release in product applications where only smooth contour features are defined.

DISCUSSION

Scope and Purpose

The purpose of this study was to evaluate the foam molding process for environmental and technical improvements. Specifically, it was to determine a nonhazardous replacement solvent for the flushing of foam mixing heads, to characterize the aluminum oxide-filled foam process, and to evaluate potential tooling improvements.

The scope of this work focused on utilizing nonhazardous replacement materials for the tricarboxylic acid (TCA) solvent that has been used for foam mix head cleaning for many years. Fourteen solvents or combinations of solvents have been identified for investigation.

The characterization of the filled foam was limited to aluminum oxide, since it is the most common of foam fillers. Shrinkage rates for molded foams with filler loading in the 30% and 70% ranges were evaluated.

Also an evaluation of potential mold improvements was to be made. The study was to be focused on design improvements to reduce tool wear and damage.

Activity

Replacement Solvents

During a preliminary screening of candidate solvents, 24 solvents were reviewed. Nine of these solvents were selected to be evaluated in the foam dispensers. Based on performance and degree of hazard, DBE-2 was selected as the replacement solvent.

Characterization of Filled Foams

Filled polyurethane foams are used as ballasts in selected weapon assemblies. Due to the low number of products produced in the filled foam category, this material had not been characterized for shrinkage rates. Production required several mold iterations before an accurate shrinkage rate could be incorporated into the mold design. This resulted in high scrap and rework rates. The effect of the process parameters on the overall shrinkage rate was also uncertain. Filled foam product prompted the characterization of aluminum oxide-filled foam.

A shrinkage study was initiated to evaluate the effects of cure temperature and cure time on the overall shrinkage rate of filled foam at filler loading rates of 30 and 70 weight percent. The cure temperatures were to range from 75°F to 325°F, and cure times to be evaluated were 3 hours and 8 hours. The foam material was mixed using a Conn-type mixing blade, with speed sufficient to thoroughly mix the components. The mixed material was then poured into an open

cavity "test block" mold of dimensions 6 in. x 6 in. x 1 in. The mold lid was secured and the foam was allowed to gel approximately ten minutes prior to the start of the oven cure.

Upon completion of the cure, the block was demolded and identified. The block was then measured using a "test block" gage fixture. The gage has six dial indicators, three that read the block dimension in the axis parallel to foam rise and three in the axis perpendicular to the foam rise. The dial indicators are calibrated to 6.000 in. using a gage master. The molded blocks are then inserted in the gage fixture where an accurate dimension can be read. This dimension was recorded. The blocks were then held in an environment of less than 15% RH to avoid expansion due to moisture pick-up.

The blocks were remeasured periodically and a differential shrinkage was calculated. This differential was then divided by the nominal mold cavity to determine an actual shrinkage factor.

Table 1 illustrates the shrinkage rates for molds with a preheat of 75°F. Several conclusions can be made by reviewing this data. First, as with unfilled polyurethane foams, the shrinkage rate is greatly affected by the cure temperature. Shrinkage rates for foams cured at room temperature are 30 to 40 times less than those for foams cured at 325°F. Secondly, the higher filler loading appears to affect the shrinkage rate by a factor of two.

The decreased shrinkage at higher loading is the result of the increased density of the product at the higher loading and the lower percentage of foam in the sample. As you move toward a maximum filler content, the foam becomes more of a binder and tends to lose the characteristic foam properties.

Third, as is typical with unfilled foam systems, the cure time had little effect on the shrinkage rate. Cure temperature is the controlling parameter. Finally, in evaluating the shrinkage rate parallel and perpendicular to the foam rise, there appear to be only minor differences.

A second set of data was tabulated for "test blocks" molded at a preheat temperature of 115°F. The same general conclusions can be drawn for evaluating this data. There does appear to be a slight increase in the total amount of shrinkage when comparing blocks cured at the same temperature and cure time while having different mold preheats. The shrinkage rates for molds preheated at 115°F are illustrated in Table 2.

Total block shrinkage as a function of time can be found in the figures in the Appendix. These data graphs depict the leveling off of the differential shrinkage at around 20 days. For the majority of parameter sets the initial shrinkage at day zero (that is the difference between cavity dimension and product dimension after block has cooled to room temperature) represents 80 to 90 percent of the total block shrinkage.

Mold Improvements

Several items were investigated as potential foam mold improvements. One item was to review the potential of applying a permanent type of coating or mold release that would eliminate the

Table 1. Shrinkage Rate Summary for Filled Foams (For Molds Preheated at 75°F)

<u>Percent Loading</u>	<u>Cure Temperature (°F)</u>	<u>Cure Time (h)</u>	<u>Shrinkage Rate Parallel to Rise</u>	<u>Shrinkage Rate Perp. to Rise</u>
30	75	N/A	0.00092	0.00046
30	125	3	0.00192	0.00150
30	125	8	0.00190	0.00150
30	165	3	0.00328	0.00230
30	165	8	0.00280	0.00257
30	200	3	0.00383	0.00302
30	200	8	0.00393	0.00300
30	250	3	0.00615	0.00448
30	250	8	0.04633	0.00418
30	325	3	0.00563	0.00537
30	325	8	0.06067	0.00573
70	75	N/A	0.00013	0.00025
70	125	3	0.00086	0.00048
70	125	8	0.00063	0.00008
70	165	3	0.00123	0.00063
70	165	8	0.00080	0.00080
70	200	3	0.00248	0.00385
70	200	8	0.00223	0.00298
70	250	3	0.00299	0.00405
70	250	8	0.00312	0.00370
70	325	3	0.00342	0.00263
70	325	8	0.00302	0.00415

extra handling involved when applying mold release after every mold cycle. A permanent coating would also eliminate the waste associated with mold preparation operations.

A coating called "NiFluor" was applied to a mold of complex configuration and to one of simple configuration. The "NiFluor" coating is a surface treatment that combines submicron particles of polytetrafluoroethylene (PTFE) with autocatalytically applied nickel/phosphorus. According to vendor literature, the PTFE is evenly distributed and locked into the nickel phosphorus matrix. If wear occurs, fresh particles of PTFE are exposed to keep the surface lubricated throughout the life of the coating.

Product molded from the simple configuration mold with the NiFluor treatment was fairly successful. The product was easily removed from the mold without additional mold release. Sufficient mold cycles were not completed to evaluate the long-term durability of the coating.

Table 2. Shrinkage Rate Summary for Filled Foams (For Molds Preheated at 115°F)

<u>Percent Loading</u>	<u>Cure Temperature (°F)</u>	<u>Cure Time (h)</u>	<u>Shrinkage Rate Parallel to Rise</u>	<u>Shrinkage Rate Prep. to Rise</u>
30	75	N/A	0.00120	0.00140
30	125	3	0.00258	0.00393
30	125	8	0.00267	0.00367
30	165	3	0.00318	0.00433
30	165	8	0.00302	0.00432
30	200	3	0.00382	0.00528
30	200	8	0.00416	0.00488
30	250	3	0.00596	0.00620
30	250	8	0.00503	0.00645
30	325	3	0.00667	-
30	325	8	0.00608	-
70	75	N/A	0.00058	0.00167
70	125	3	0.00160	0.00216
70	125	8	0.00483	0.00283
70	165	3	0.00173	0.00217
70	165	8	0.00170	0.00132
70	200	3	0.00100	-
70	200	8	0.00027	0.00035
70	250	3	0.00172	0.00082
70	250	8	0.00172	0.00146
70	325	3	0.00233	0.00160
70	325	8	0.00246	-

The mold of complex configuration was much different. Removal of the product from this mold was extremely difficult, especially where there were male features longer than one inch in the mold. In an attempt to ease the amount of friction on molding surfaces, higher mold strip temperatures were evaluated. This proved unsuccessful as well. A small amount of carnuba wax type mold release was then applied to the "NiFluor" surface. After the addition of the mold release, the molded parts released successfully.

It appears for complex configurations that a minor amount of mold release would be required with the "NiFluor" coating to consistently demold product successfully. Since this application would be highly subjective, it is not considered to be a viable option for most molds. However, for products with simple contours and where small friction surfaces exist, the coating would be all that is required.

Recommendations

It is recommended to replace the chlorinated solvent with DBE-2 (incorporated in CY90) and to utilize the NiFluor coating as a mold release in product applications where only smooth contour features are defined.

Implementation of these recommendations will reduce the amount of waste generated in the Foam Molding operation and lower the risk of exposure to hazardous chemicals.

Accomplishments

The following accomplishments were achieved:

- Identified a nonhazardous substitute solvent for TCA in foam mixing machine applications,
- Characterized foam shrinkage rates for polyurethane foams filled with aluminum oxide, and
- Determined applicability of permanent coatings as a mold release for foam molds.

Future Work

The nature of the shrinkage data for the filled foams would indicate that the cure temperature and filler loading rates are the most significant parameters in determining shrinkage. Additional blocks in a filler loading between 30 weight percent and 70 weight percent should be done to determine if the shrinkage decrease as a function of filler loading is a linear relationship.

Additional work needs to be conducted in the area of mold release coatings. The long-term durability of the "NiFluor" coating needs to be investigated further. If the coating does not have good wear properties, it may not be sufficient for product of simple configuration.

APPENDIX
Material Shrinkage Profile Plots

Shrinkage as a Function of Time

BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 75 deg. F.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp = 125 deg. F.

Cure Time = 3 hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 125 deg. F.
 Cure Time = 8 hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 165 deg. F.

Cure Time = 3 hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 165 deg. F.

Cure Time = 8 hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 200 deg. F.
Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 200 deg. F.
Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 250 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 250 deg. F.
Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 325 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 325 deg. F.

Cure Time = 8hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 75 deg. F.
 Cure Time = -hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 125 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 125 deg. F.

Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 165 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 165 deg. F.

Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 200 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 200 deg. F.

Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 250 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time

BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 250 deg. F.
Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 75 deg. F. Cure Temp. = 325 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 1/2 deg. F. Cure Temp. = 325 deg. F.
 Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 75 deg. F.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp = 125 deg. F.
 Cure Time = 3 hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 125 deg. F.

Cure Time = 8 hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 165 deg. F.

Cure Time = 3 hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 165 deg. F.
 Cure Time = 8hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 11½ deg. F. Cure Temp. = 200 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 200 deg. F.

Cure Time = 8hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 250 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 250 deg. F.

Cure Time = 8hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 325 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 30% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 325 deg. F.
 Cure Time = 8hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 75 deg. F.

Cure Time = -hrs.

Shrinkage as a Function of Time

BX44306--70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 125 deg. F.
Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 125 deg. F.

Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 165 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 165 deg. F.
 Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 200 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 200 deg. F.

Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 250 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 250 deg. F.

Cure Time = 8hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 325 deg. F.

Cure Time = 3hrs.

Shrinkage as a Function of Time
BX44306-70 Foam Loaded with 70% Aluminum Oxide

Preheat = 115 deg. F. Cure Temp. = 325 deg. F.

Cure Time = 8hrs.