

Recovery of expanded polystyrene from coated patterns rejected from lost foam casting

J. Pletka and J. Drelich

Graduate student and assistant professor, respectively, Department of Materials Science and Engineering, Michigan Technological University, Houghton, Michigan

Abstract

Lost foam casting is a process in which a polymeric material is formed into the shape of the part to be cast. Parts that are more complex are fabricated by simply gluing several patterns together. The pattern is then coated with a refractory material consisting of a mineral mixture and binders. Finally, hot metal is poured into the pattern, evaporating the expanded polystyrene and taking the shape of the coating shell. Prior to casting, a significant number of the patterns are damaged and inevitably landfilled. In this study, a process was developed for the recovery of expanded polystyrene from the coating and glue contaminants. The process consists of shredding, impact comminution, size classification and pneumatic separation. It is successful in separating up to 97% of the contaminants, while recovering 95% of the polystyrene.

Key words: Casting, Lost foam process, Expanded polystyrene recovery

Introduction

Lost foam casting is still a relatively new technology and is gaining confidence among manufacturers. Lower machining requirements on castings and higher surface qualities have led to an overall decrease in manufacturing costs, which has bolstered its use in recent years. In 1997, 127,600 t (140,700 st) of aluminum, iron and steel (of which aluminum is a majority) were cast using lost foam technology. A recent market study indicated that production would increase by 83% to 250,000 t (256,800 st) in 2000 (Margolis et al., 1997).

Lost foam casting is a process by which hot metal displaces a polymer pattern and takes the shape of a coating shell. Figure 1 shows a schematic of the process. For aluminum castings, the polymer pattern is composed of expanded polystyrene. Generally, the part exceeds the complexities that expanded polystyrene beads can be molded. Consequently, simple shapes are molded and subsequently assembled with an adhesive. The assembly is then coated with a refractory material consisting of a mineral mixture (primarily silica or mica and clay materials) and a polymeric binder. Finally, the coated casting pattern is compacted with sand to provide strength, and hot metal is poured into the mold through a gating system. The hot metal vaporizes the polystyrene (which is absorbed through the porous coating into the sand) and takes the shape of the coating shell.

The coating is engineered to obtain a variety of properties imperative to the casting process, including thermal insulation, liquid absorption, controlled permeability and abrasion resistance (Hunter, 1998). However, the coating is relatively

brittle and susceptible to damage, which may occur in the handling or storage of coated patterns. Also, residual blowing agents remaining in the polystyrene pattern volatilize and change the shape of the pattern, which can crack the coating; once the coating is damaged, the casting pattern is no longer usable and is disposed in a landfill. As the volume of castings produced by lost foam increases, the disposal of rejected casting patterns becomes an environmental as well as an economic issue.

The disposal of rejected casting patterns presents the loss of a valuable resource, i.e., polystyrene. The beneficiation of expanded polystyrene from rejected casting patterns cannot only reduce disposal costs and the environmental impact, but also recycle polystyrene back into the consumer market. However, the process to beneficiate polystyrene must be practical and inexpensive. It is, therefore, of interest to develop an inexpensive, reliable and flexible process to recover expanded polystyrene from rejected casting patterns. It is not of interest to recover and recycle the coating and adhesive components, as they have no perceived value as recycled materials.

The rise in use of lost foam casting has recently precipitated interest in solving a potential problem in the disposal of rejected casting patterns. As such, this work represents the first attempt at developing a technology on the recovery of expanded polystyrene from rejected casting patterns. Therefore, the focus of research was not simply on the development of the technology, but also on developing an approach in line with the goals of industry; develop an inexpensive process that is easily applicable to full-scale operation.

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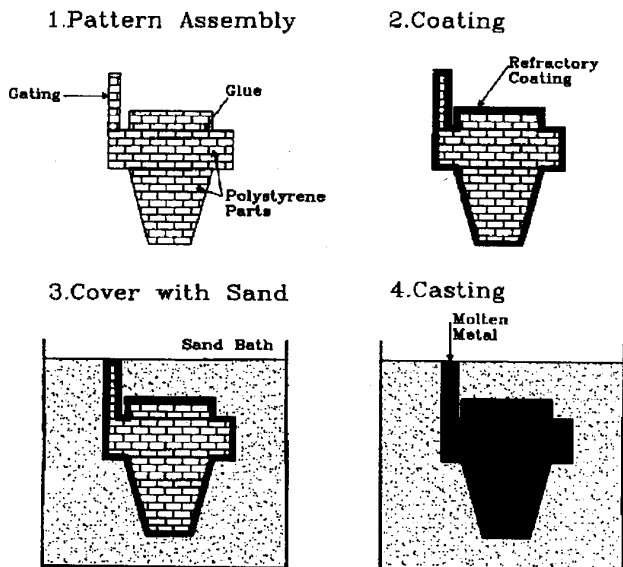


Figure 1 — Schematic of lost foam casting.

Table 1 — Some properties of the glue, coating and expanded polystyrene components of rejected lost foam patterns.

Constituent	Wt%	Density, kg/m ³
Expanded PS	35	36-25
Coating	63	2,670
Glue	2	920

Several approaches were considered in varying degrees. One such approach involves the selective dissolution of polystyrene in an organic solvent. However, this approach has several fundamental drawbacks. First, it is likely that any organic solvent for polystyrene will, to some degree, attack the other organic compounds (glue and polymeric binder in the coating). For example, toluene readily dissolves polystyrene but also dissolves a portion of the glue, albeit at a much slower rate. Organic solvents also tend to be volatile, and a containment system would be required to prevent losses. Conversely, a separation based on component density works quite well while allowing the processing steps to remain relatively simple. The densities of each component are listed in Table 1. As Table 1 shows, there is a drastic difference in densities between the expanded polystyrene and the glue and coating. Accordingly, all experimentation in the development of a technology for the recovery of expanded polystyrene from rejected casting patterns focused predominantly on density based separations. The work presented in this paper primarily focuses on the separation of the coating from expanded polystyrene.

Experimental

The experimental work performed for the development of a process technology for the recovery of polystyrene from rejected casting patterns consists of size reduction, measurement and analysis of particulate size distributions, screening, impact comminution and density-based separation.

Measurement techniques. To evaluate the coating content of a sample, a technique was devised similar to that used for measuring the amount of volatile material in coal. The analysis consists of burning the volatile glue and polystyrene and weighing the remaining coating. A sample containing polystyrene, coating and glue was subjected to a temperature of 460°C for 20 min in an enclosed crucible. After 20 min, the furnace was ramped to 600°C at an average rate of 4° to 5°C per minute. The samples were removed after a total of 70 min and set to cool in a desiccator. After cooling, the samples were weighed on a microbalance. The coating contains polymeric binders that also volatilize in the ashing procedure along with the polystyrene and glue. To determine the weight of coating (A) in an ashed sample, a curve was prepared, where the ash (B) is related to the coating weight according to

$$A = 1.0735B + 0.0021 \quad (1)$$

Note that this procedure does not distinguish between polystyrene and glue and that it only calculates a weight percent of coating. The glue content is estimated by the selective dissolution of polystyrene in an organic solvent and treating the remaining glue/coating mixture with the ashing procedure described above.

Shredding. The rejected casting patterns were shredded with a rotary-style granulator. This type of granulator uses a set of knife blades that rotate at a high rpm to shear the patterns into a particulate form. The cutting chamber includes an exit screen to control the top particle size of shredder product. Tests were performed with exit screens with aperture diameters of 25.4, 19.1, 12.7 and 6.35 mm (1.0, 0.75, 0.50 and 0.25 in.). Shredding was performed in batches of a minimum of 1,000 g to ensure a constant composition.

Size distributions. The size distributions of coating, polystyrene and liberated glue from shredded casting patterns were individually determined. This was accomplished by sieving 400- to 500-g samples on a stack of sieves following a root-2 progression from the top particle size to 65-mesh (0.212 mm) on the Tyler scale. Due to the large volume exhibited by a 400- to 500-g sample, material was sieved in smaller sized batches of about 40 to 80 g, depending on the range of size distribution for 20 min each.

Each size fraction was then subjected to a two-stage sink/float procedure; the first stage was performed in water, while the second stage was performed in ethanol. The first stage consisted of immersing the material in a water bath followed by 2 to 5 min of gentle agitation. The dense material was allowed to settle for 5 to 10 min followed by removal of the floats. The floats consist of a mixture of PS and liberated glue, because glue has a density slightly less than water. The floats were then dried and subjected to a second float/sink stage in ethanol, which has a specific gravity of 0.79. The liberated glue would sink after following a similar procedure as described above for float/sink water testing. The liberated glue was dried, weighed and added to the coating-rich water sinks for ash analysis, where the weight percent of liberated glue was determined.

Impact comminution. Impact comminution denotes the application of high stresses at high speeds to particulate material. This type of crushing is often used for soft and friable materials such as limestone (Wills, 1992). A hammer mill, which utilizes impact-type breakage, consists of striking bars

that impart the stress to the particles and have a plate screen to control the exiting particle size. The hammer mill used for rejected casting patterns is equipped with three 25-mm-wide, 450-mm-long rotating paddles. These swing freely about pivot points and require a minimum rpm of 500 to maintain suspension in air.

Coarse material (+6.35 mm) was subjected to impact comminution. Each test was performed in a batch manner on a representative sample of 25 g. A factorial design was used to measure the effects of mill residence time and mill rpm (impact force) on coating removal. Nine combinations were performed at 500, 1,000 and 1,500 mill rpm and at 30, 60 and 90 seconds of residence time. The product from each test was subjected to size classification on an 8-mesh screen. Each combination was replicated. All 18 runs were performed in random order. The feed material contained 9.0% (by weight) coating.

Pneumatic separation. Separation of coating and glue from polystyrene particles was facilitated with an air-gravity settling box (Fig. 2) as designed and constructed in this project. The settling box consists of a 510- by 510-mm tunnel extending a total of 2,440 mm in length and is divided into two sections, each 1,220 mm in length. The first section serves the purpose of not only housing the fan but also to straighten the flow and provide a more uniform velocity profile. These are extremely important considerations for the design of the settling box. Preliminary experiments showed that expanded polystyrene is very sensitive to local disturbances (turbulence) in the air stream due to its extremely light density. Therefore, air streams with a high degree of turbulence tended to settle polystyrene almost at random distances, rather than at distances characteristic of the particles. To reduce turbulence, a bladed fan was used.

Rejected casting patterns shredded to -6.35 mm were subjected to separation in the settling box. Samples of 200 g were fed to the settling box at an average feed rate of 3.3 g/min and an average air velocity of 2.0 m/s. The material settled into seven sections in the box: six equally spaced sections comprised of 203-mm lengths plus the material that overflowed the entire section onto a table outside of the box. Each of the sections was then separated into size fractions ranging from 4-mesh (4.75 mm) to 20-mesh (0.85 mm) following a root-2 progression.

Results and discussion

Shredding. Shredding serves the dual purpose of liberating coating and glue from the polystyrene, while reducing the rejected casting patterns to a manageable size. It was observed that shredding with 25.4-, 19.1-, 12.7- and 6.35-mm aperture-diameter exit screens liberated in excess of 95% of the coating in all cases. Figure 3 shows the percent coating liberation as a function of exit screen size. As expected, the percentage of coating liberation increases with a decreasing size in exit screen aperture diameter (particle top size). However, the improvement in liberation is not very significant, as it is in the range of only 2%.

Size segregation. A histogram representing the size distribution of polystyrene, coating and liberated glue from shredded material passing the 19.1-mm exit screen is shown in Fig. 4. Note that the weight percent is based on the total amount of that particular constituent and is not based on the total sample weight. From Fig. 4, it is easy to see that the polystyrene tends

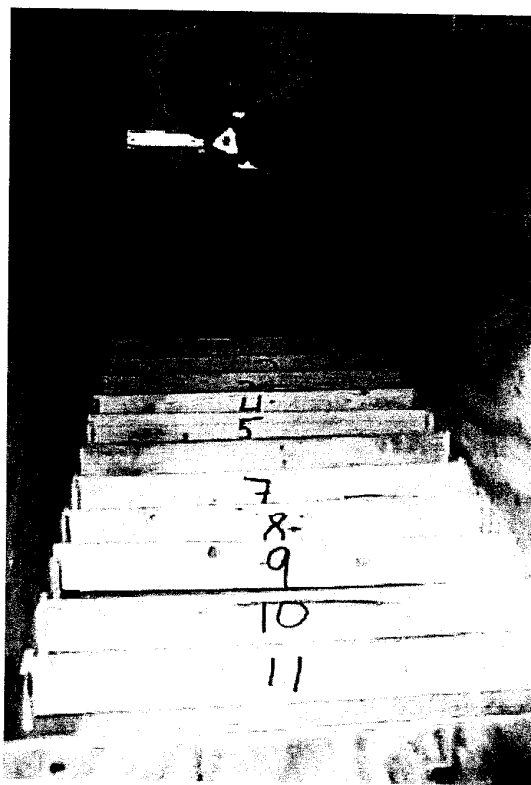


Figure 2 — Gravity settling box used in pneumatic separations.

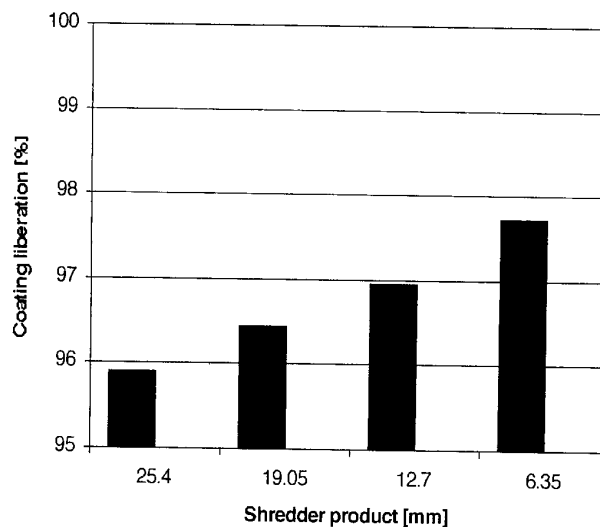


Figure 3 — Percent coating liberation of shredder products (6.35, 12.7, 19.1 and 25.4 mm).

to segregate to coarser size fractions, while the coating and liberated glue constituents segregate to finer size fractions. The size segregation of polystyrene from the other components suggests that a large amount of coating and liberated glue can be separated by simply screening out the fine size fractions with a minimal loss of polystyrene. It turns out that size segregation is a function of the shredder exit screen

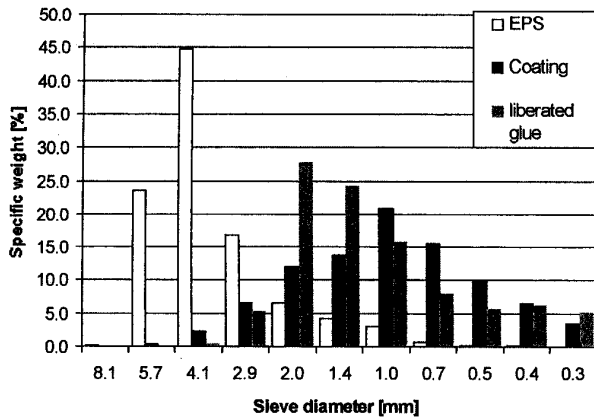


Figure 4 — Specific weight percent of the polystyrene (EPS), coating and liberated glue over all size fractions for the 6.35-mm granular product.

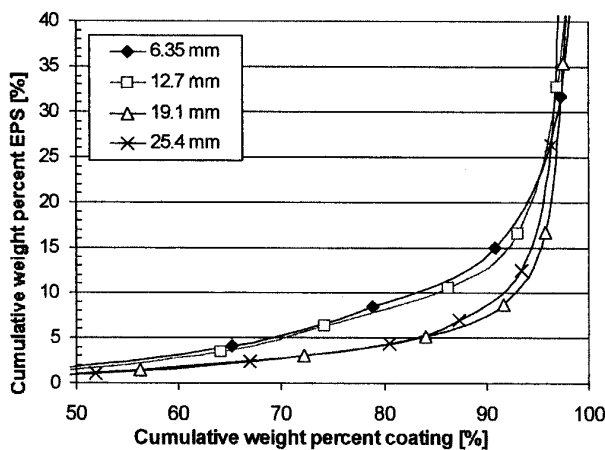


Figure 5 — Cumulative weight percent polystyrene vs. cumulative weight percent coating of the 6.35-, 12.7-, 19.1- and 25.4-mm shredder products.

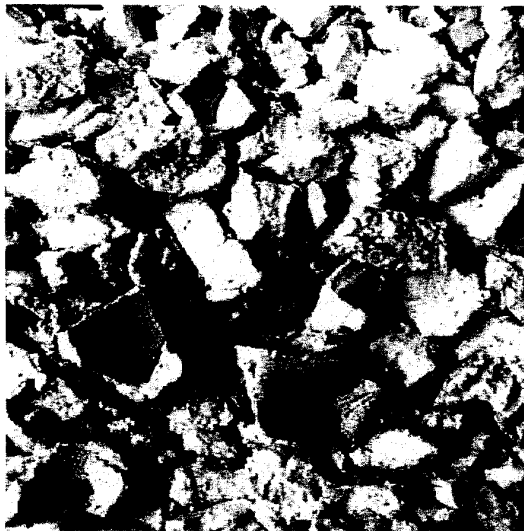


Figure 6 — Coarse polystyrene particles (+6.35 mm) exhibiting unliberated coating

Table 2 — Some characteristic values of cumulative percent coating passing with 5% and 10% passing polystyrene for material shredded past a 6.35-, 12.7-, 19.1- and 25.4-mm exit screen.

Aperture diameter of exit screen, mm	Particle size, mm			
	5%	10%	5%	10%
25.4	86	92	3.4	5.0
19.1	86	93	3.1	4.3
12.7	73	85	1.8	2.9
6.35	72	83	1.7	2.2

aperture diameter. This can be seen in Fig. 5, where a plot of the cumulative percent passing polystyrene against cumulative percent passing coating for the 6.35-, 12.7-, 19.1- and 25.4-mm shredder products is displayed. Table 2 lists some values from Fig. 5. Notice that for the 25.4- and 19.1-mm shredded material, the particle size that passes 5% of the polystyrene also passes 86% of the coating. On the other hand, the 12.7- and 6.35-mm shredded material passes only 73% and 72% of the coating, which is 13% to 14% less than that obtained with the 25.4- and 19.1-mm shredded material, respectively. Therefore, shredding with a 19.1- or 25.4-mm exit screen provides a distinct advantage; disposal of fine size fractions will contain a minimal amount of polystyrene, maximizing recovery, while removing a majority of the coating.

Impact comminution. The size distributions represented in Fig. 4 show that a very small amount of coating is retained in coarse size fractions. In fact, almost all of the coating present in coarse size fractions is unliberated (75%). Figure 6 shows a picture of some coarse polystyrene particles with unliberated coating. The application of impact type stresses to these particles tends to selectively break the coating from the coarse polystyrene particles. Under impact stressing, the polystyrene particles tend to deform as the cell structure compresses. The coating adhering to the polystyrene, on the other hand, cannot withstand the deformation, cracks and is released from the polystyrene particle. Because the coarse polystyrene particles are not dramatically reduced in size, the coating can then be removed by subsequent screening.

The coarse size fractions (+6.35 mm) from material shredded through a 25.4-mm exit screen was subjected to comminution in the hammer mill. Figure 7 plots the resulting coating weight percent after milling for 30, 60 and 90 seconds at a mill speeds of 500, 1,000 and 1,500 rpm and shows a progressive decrease in weight percent coating with an increase in mill speed. Mill speeds at 1,000 and 1,500 rpm remove more than 75% of the coating, yielding a product of less than 1.5% (by weight) coating. From Fig. 7, it is also easy to see that time, over the range chosen for experimentation, has very little effect on the removal of the coating.

Pneumatic separation. The densities shown in Table 1 indicate that the separation of expanded polystyrene from the coating and glue is feasible. However, separations based on density are also sensitive to particle size, shape and surface roughness. The coating is characteristically platelike, with a variable aspect ratio (coating particle diameter to thickness

ratio) that is as high as 25 to 1, but is on average 5 to 1. Consequently, in an air stream the coating will behave like a lighter particle than predicted by density alone.

The combination of a high aspect ratio and a wide size distribution does not result in a clean separation of expanded polystyrene from coating and glue particles in the air-gravity settling box, which is not very surprising. However, about a third of the coating is cleanly separated. This fraction primarily consists of coarse material with low thickness-to-diameter ratios. The remainder of the coating tends to overlap with polystyrene in all of the other bins. Due to the density differences between the coating, glue and polystyrene, the coating and glue tend to have smaller sizes than the polystyrene within each bin. Therefore, subjecting each bin to size classification by screening yields a polystyrene concentrate. Figure 8 shows a percent recovery of expanded polystyrene vs. weight percent coating plot for the third bin. Each data point represents the percentage of polystyrene retained on a screen with the indicated mesh number and the grade of the material in terms of weight percent coating. For example, the data point marked +8-mesh (+2.36 mm) indicates that 96% of the polystyrene in Bin #3 was retained on an 8-mesh screen and measures 5% (by weight) coating. On the other hand, the data point marked +10-mesh (+1.7 mm) shows that 99% of the polystyrene from Bin #3 is retained on the +10-mesh screen, but measures 10% (by weight) coating.

Notice how the curve changes from a nearly vertical slope to a zero slope between the +8- and +10-mesh data points. The vertical slope of the line between the +4-mesh (+4.75-mm) and +8-mesh data points suggests that no significant amount of coating accumulates with polystyrene up to the 8-mesh size. Conversely, the zero slope of the line from data points +10- to +20-mesh (+0.85 mm) suggest that only coating accumulates on these screen sizes. Therefore, if Bin #3 is screened with an 8-mesh screen, a maximum amount of expanded polystyrene can be recovered with a minimum amount of coating. A similar analysis was performed for all the other bins (except for the first bin, which contained only coating and glue) as shown in Fig. 9. Overall, 95% of the polystyrene was recovered. The grade of the polystyrene measured 2% (by weight) coating, which indicates that in excess of 99% of the liberated coating was separated.

Conclusions

Based on the results obtained from laboratory-scale experiments, a process flowsheet was developed for the removal of coating and glue from rejected casting patterns. A schematic of this flowsheet is shown in Fig. 10. Rejected casting patterns that consist of expanded polystyrene, glue and coating are fed into a shredder, which reduces the patterns into a particulate form of a manageable size. Coating and liberated glue segregate to fine particle sizes (-1.18 or -0.85 mm) and can simply be discarded. Furthermore, size segregation can be optimized by shredding the rejected casting patterns to relatively coarse sizes (-25.4 or -19.1 mm). Coarse material (+6.35 mm) predominately consists of polystyrene particles with little coating. The coating that is present in the coarse size fractions is unliberated and is subject to selective milling in a hammer mill, which was successful in reducing the coating to less than 1.5% (by weight). The intermediate size fractions contain a mixture of coating, glue and polystyrene and can be separated by pneumatic separation. Pneumatic separation was demonstrated to separate in excess of 99% of the contaminants, yielding a product assaying 2% (by weight) coating.

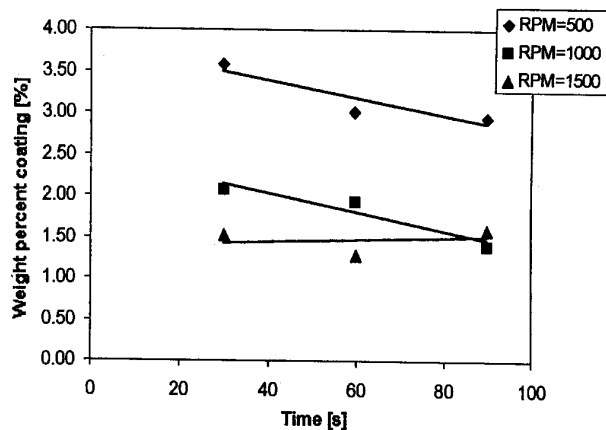


Figure 7 — Effect of mill rpm and residence time on product grade.

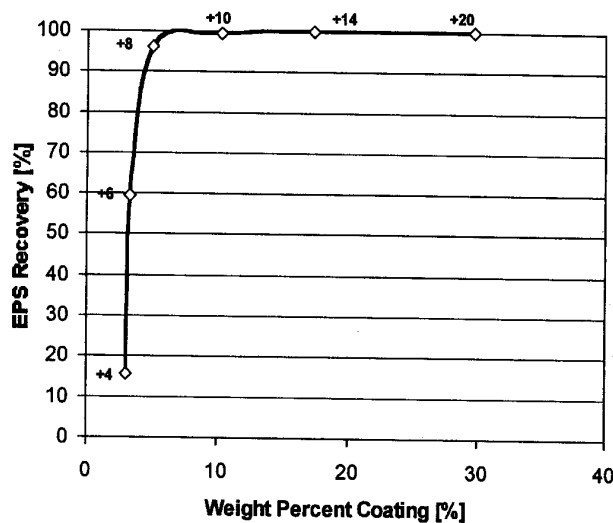


Figure 8 — Grade-recovery relation in settling box Bin #3. Product grade expressed in terms of coating percent by weight.

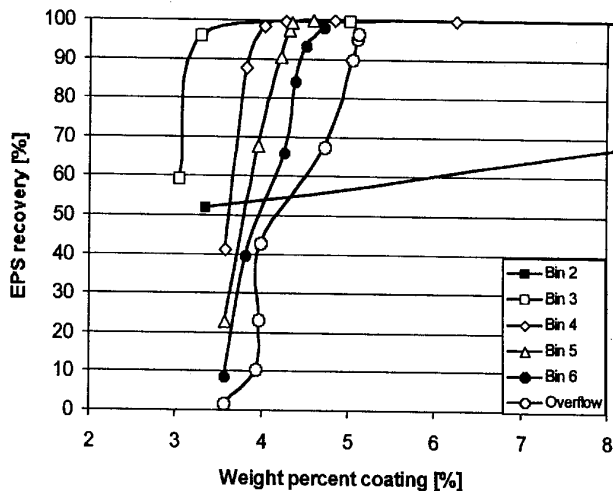


Figure 9 — Grade-recovery curves over all settling bins.

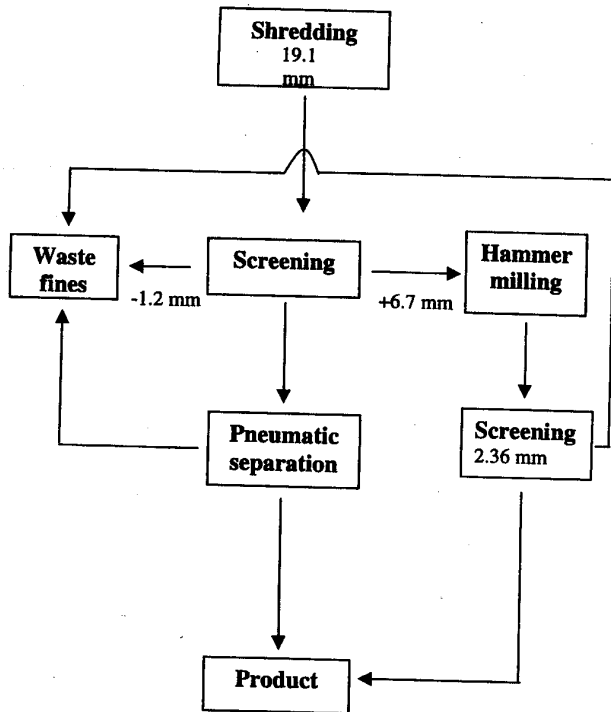


Figure 10— Schematic flowsheet of proposed technology for the recovery of expanded polystyrene from rejected lost foam casting patterns.

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