WRAP MDD018/23 WEEE separation techniques

Pallmann differential impact milling trial report

Abstract

This report details a trial conducted on an impact mill at Pallmann for WRAP project MDD018/23. The aim of the project was to trial innovative techniques to tackle some of the more difficult separations encountered by primary and secondary WEEE processors.

The aim of the trial was to evaluate the potential for using differential size reduction, based on varying impact strength of polymers in order to separate comingled material into its component parts.

It was possible to demonstrate that differential size reduction does occur, but the degree of separation achieved with this system was too low to be commercially significant for the sector.

The degree of separation achieved could be improved by using input material with a larger particle size. The generation of fines from both components means that the finer fraction from the more brittle material would probably always suffer from a degree of contamination from the tougher material.

The Pallmann mill did however prove to be good at delaminating co-bonded PS and elastomer.

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1.0 Trial information

Trial host: Pallmann Maschinenfabrik GmbH & Co. KG. The trial was conducted at a test facility in Zweibrücken, Germany.

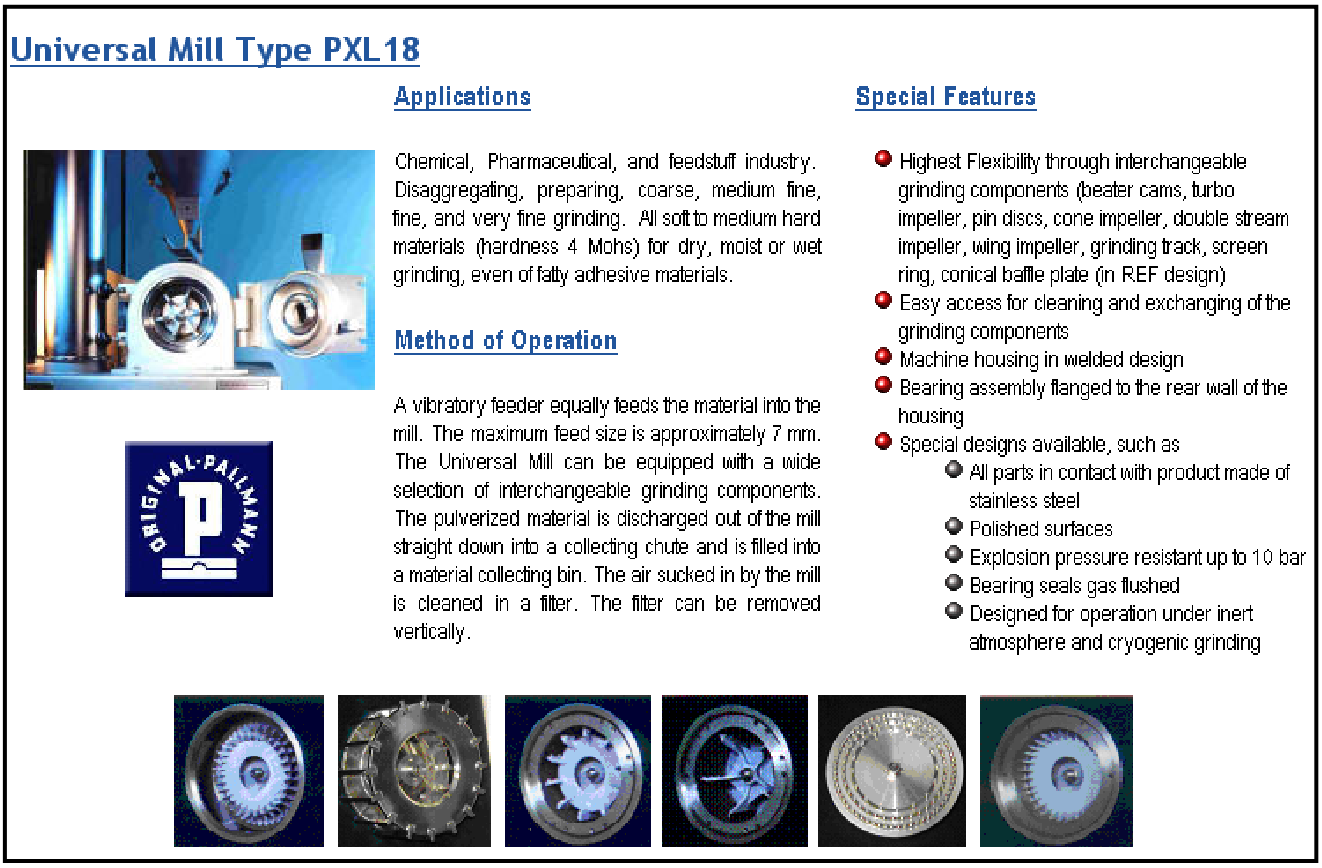
Trial equipment: Pallmann PXL18 Mill

Trial date: 20th January 2009

1.1 Description of trial equipment

The Pallmann PXL18 with a "Schlagnasen" Mill (*Figures 1 and 2*) is a coarse rotor-stator mill with two rings of elements (four inner and eight outer) on the rotor and a single ring of eight elements on the stator (*Figure 3)*. The maximum rotor speed was limited with these rotor stator discs to 12,000 rpm. Pin mill discs could have been run faster, but there were significant concerns about both pin strength and also the potential to blind off the relatively closely spaced pins.

The nominal capacity of the mill is ~30kg/hr, but this figure is highly dependent on the material type and the particle size distribution of the feed material.



Universal Mill Type PXL18

Applications

Chemical, Pharmaceutical, and feedstuff industry. Disaggregating, preparing, coarse, medium fine, fine, and very fine grinding. All soft to medium hard materials (hardness 4 Mohs) for dry, moist or wet grinding, even of fatty adhesive materials.

Method of Operation

A vibratory feeder equally feeds the material into the mill. The maximum feed size is approximately 7 mm. The Universal Mill can be equipped with a wide selection of interchangeable grinding components. The pulverized material is discharged out of the mill straight down into a collecting chute and is filled into a material collecting bin. The air sucked in by the mill is cleaned in a filter. The filter can be removed vertically.

Special Features

- Highest Flexibility through interchangeable grinding components (beater cams, turbo impeller, pin discs, cone impeller, double stream impeller, wing impeller, grinding track, screen ring, conical baffle plate (in REF design)
- Easy access for cleaning and exchanging of the grinding components
- Machine housing in welded design
- Bearing assembly flanged to the rear wall of the housing
- Special designs available, such as
  - All parts in contact with product made of stainless steel
  - Polished surfaces
  - Explosion pressure resistant up to 10 bar
  - Bearing seals gas flushed
  - Designed for operation under inert atmosphere and cryogenic grinding

Figure 1: PXL18 MILL Introductory Data Sheet (REFERENCE: http://www.pallmannpulverizers.com/pxl_18_pharma_design_pulverizer.htm)

1.2 Photographs of trial equipment

Figure 2: Photograph of the PALLMANN - PXL18 Mill

Figure 3: Photograph of the PXL18 Mill Rotor (8 elements on outer ring and 4 elements on inner ring) and Stator (8 element ring)

1.3 Trial objectives

The objective of the trial was to explore the potential to exploit the varying levels of brittleness of different polymers, in order to be able to separate polymer mixtures. In an ideal case the milling would result in the more brittle material being so small that its entire size distribution curve would be lower than the tougher component, meaning that they could be separated by sieving or a similar size exclusion technique.

Two groups of materials were trialled:

- Pairs of thermoplastics with different impact properties ; and
- Thermoplastics and elastomers.

Each type of material was made of a different colour so as to make subsequent identification of material type simpler.

This technique is particularly interesting for ABS and PS, which are often found as comingled materials and are difficult to separate with established techniques.

1.4 Sample material and preparation

The specific grades of material used in the trial are:

- Axion recycled high impact polystyrene (HIPS) grade PS02 (black) – 400 kg;
- Virgin Acrylonitrile Butadiene Styrene (ABS) Taita 1000 (white) – 150 kg;
- Virgin Polypropylene (PP) K402 (red) – 150 kg; and
- Trouser Hanger Clips (mixture of styrene and rubber) – 100 kg.

The PP, ABS and PS were moulded into 25.4mm diameter fax roll cores by Denroyd, an injection moulding company, with automatic separation of the sprue in order to give two fractions of material with different aspect ratios. These fractions were then granulated at Axion's Salford factory using a 12mm screen as the maximum particle size recommended by Pallmann was 8mm. This produced a feed material with an average particle size of around 5mm and an effective maximum particle size of 8mm.

The granulated materials were also run through an air separator at Axion Polymers to remove any fines, in order to improve the potential separation of the size reduced larger fraction after milling.

The coat-hanger clips (composite items with rubber bonded to PS) were also granulated (*Figure 10*) prior to the main Pallmann trial, without any other preparation (moulding). The composition of the coat hangers was 17% elastomer and 83% PS.

By processing the PP, ABS and PS cores and sprues separately it was possible to produce two fractions of material, with different aspect ratios, from the same injection moulding process. The aspect ratio of the granulated cores was significantly higher than that of the sprues.

Figure 4: Granulated PS02 Sprues

Figure 5: Granulated PS02 Tubes

Figure 6: Granulated ABS Sprues

Figure 7: Granulated ABS Tubes

Figure 8: Granulated PP Sprues

Figure 9: Granulated PP Tubes

Figure 10: Granulated Coat-Hanger Clips

2.0 **Trials**

2.1 Initial assessment of milling performance

The first step in assessing the process parameters for the equipment was to run a series of short tests to establish the optimal rotor speed for size reducing each sample material. This was performed using the coat-hanger material since this sample offered the largest difference in impact behaviour between the components because one of the components was an elastomer.

Only small changes in the particle size distribution were observed during the first two runs at 6,000 and 12,000 rpm respectively and primarily this was seen with the coarser >6.3 and >8mm fractions.

The maximum particle size of 8mm recommended by Pallmann may have been too small. In defining the maximum particle size both the length and the thickness of a particle are important factors in preventing material from being caught between the rotor and the stator. Although some tangling of material in the rotor could be heard against the background mill noise this was not considered to be unusual. This means that a larger feed size could probably have been used.

Since the trial material, with the exception of the granulated sprues, was relatively flat flakes the minimum particle dimension was in the region of 2 to 3 mm and there was scope for the flakes to orientate in the rotor stator gap. That means there was probably scope to run with a larger particle size of between 12 and 16mm, which would have significantly increased the ability of the mill to size reduce the input material.

However, in order to maximize the size reduction potential available it was decided to run the mill at its highest speed of 12,000 rpm, with a relatively low feed rate to minimise the relatively low energy particle/particle impacts and maximize the more energetic rotor/stator impacts. Very little friction heating was observed, with rotor temperatures of no more than 26°C recorded during the trial.

One practical issue observed was that the relatively larger sized material exiting the mill had sufficient energy to puncture the plastic collection bags being used. The bags were replaced by a steel collection drum for safety reasons.

2.2 Milling trials of coarse sieved fraction

During the initial assessment significant size reduction was really only observed for the coarser feed material. For this reason two 5kg samples of over 6.3mm and over 8mm coat-hanger material were prepared by hand sieving.

This material was then passed through the mill a total of three times.

Significant delamination of the rubber occurred, but due to stratification effects it was difficult to obtain a representative sample and so further analysis of the milled material was undertaken after the trial.

Figure 11: Apparent elastomer-PS separation

2.3 Co-milling of polymer blends

Initially a single milling run was performed on each of the polymer pair combinations of PS/PP, PS/ABS and PP/ABS. Again as with the first two runs on the equipment, little change could be seen in the overall particle size distribution and so the samples were subjected to an additional three passes through the mill.

The reason for the multiple passes through the mill was to assess whether it was the number of impacts or the impact energy that was the dominant factor in determining size reduction. If the number of impacts dominated then it would have been possible to run the samples on a larger mill with more rotor and stator rings.

However as this proved not to be the case the trials were completed after an assessment of both the coat-hanger and PS/ABS samples, with three pass milling. The other two polymer combinations, PP/PS and PP/ABS, were run by Pallmann on the following day, without Axion present, in order to complete the trial matrix.

2.4 Trial matrix

Run	Material Type	Time/Run (min:sec)	Temp. Rotor Chamber after Run (°C)	Speed of Rotor (rpm)	Feed Rate (kg/hr)	Comments
*	PS + elastomer	06:00	21	6000	17	No apparent separation or size reduction
V1	PS + elastomer	06:00	22	12000	17	Material loss due to bag fracture
V2	PS + elastomer	10:00	26	12000	17	
V3	PS + PP	10:00	26	12000	24	
V4	PS + ABS	10:00	27	12000	36	Error in setting the feed rate
V5	PP + ABS	06:00	26	12000	60	Error in setting the feed rate
V6.1	PS + elastomer (>8)	07:30	24	12000	16	Most of the rubber seemed to stay coarse while the PS size reduced considerably
V6.2	PS + elastomer (>8)	07:02	24	12000	16	
V6.3	PS + elastomer (>8)	06:35	24	12000	16	
V7.1	PS + elastomer (>6.3)	08:41	25	12000	16	Again significant rubber separation was observed
V7.2	PS + elastomer (>6.3)	07:44	25	12000	16	
V7.3	PS + elastomer (>6.3)	05:40	25	12000	16	

V8.1	**PS + ABS**	**05:16**	**26**	**12000**	**16**	**Tentative indication of more coarse ABS** ***Runs 1, 2 and 3 of "PS + ABS"***
V8.2	**PS + ABS**	**04:02**	**26**	**12000**	**16**	
V8.3	**PS + ABS**	**02:24**	**26**	**12000**	**16**	
V9.1	**PS + PP**			**12000**	**16**	**Trials V9.1 to V10.3 were Conducted by PALLMANN technical staff without Axion supervision**
V9.2	**PS + PP**			**12000**	**16**	
V9.2	**PS + ABS**			**12000**	**16**	
V10.1	**PP + ABS**			**12000**	**16**	
V10.2	**PP + ABS**			**12000**	**16**	
V10.3	**PP + ABS**			**12000**	**16**	

2.5 Size distribution analysis

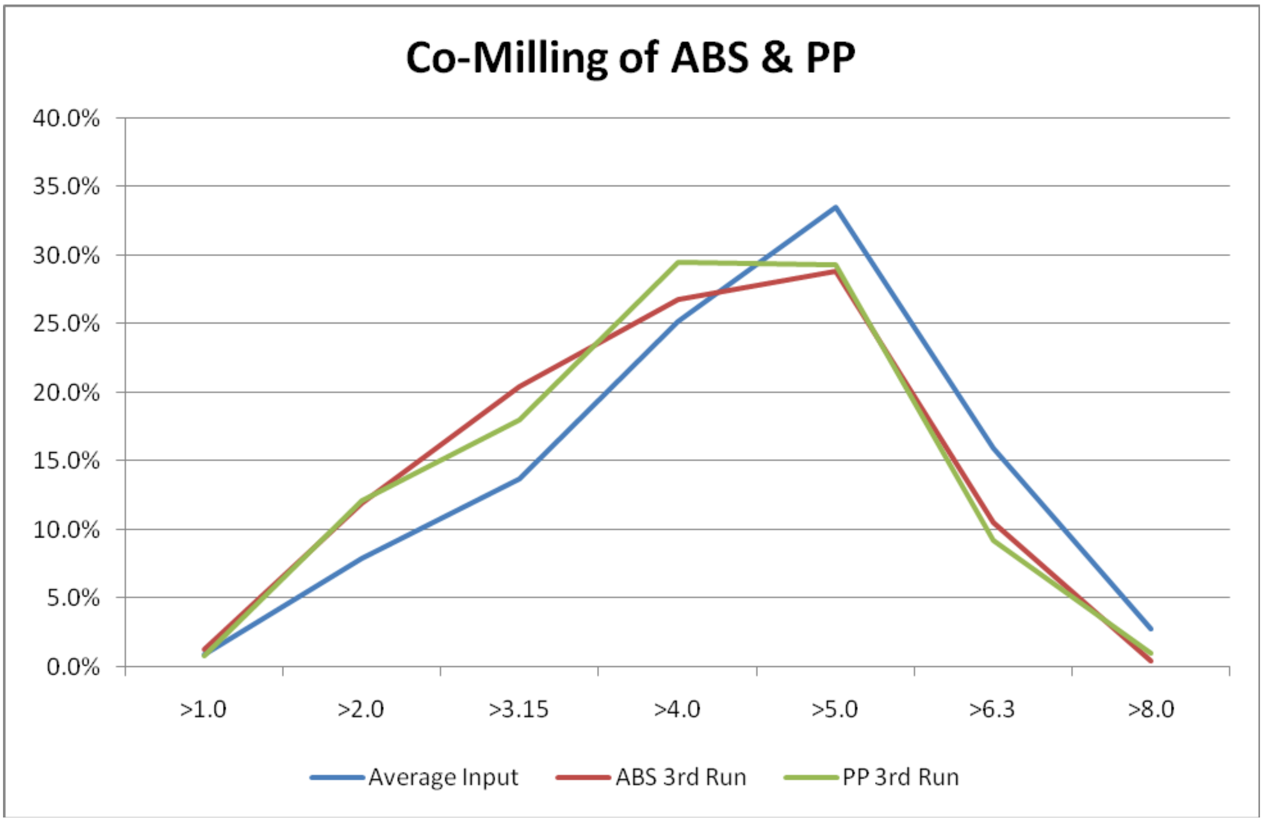
The technique used to determine the effect of the milling process was sieve analysis, using a vibrating sieve stack with a ~100g sample agitated for ten minutes. Since the testing performed at Pallmann only showed the overall particle size for both polymer components, it was necessary to perform an additional separation of the sieve size fractions. This was done by hand sorting each sieve fraction on the basis of the colour difference between the different material types and so it was also possible to obtain both the weight and the number of particles of each polymer type for a given size fraction.

One reason for doing this was to ensure that the numbers of particles in the coarser fractions were sufficient to avoid issues with sampling errors. However, it also allowed for a review of the relative average particle weight/volume between the polymer components, which might provide an insight into any possible shape variations in the size reduced material.

2.5.1 Input material

The particle size distribution of all of the input materials was broadly similar showing that very little, if any, brittle fracture had occurred in the granulator.

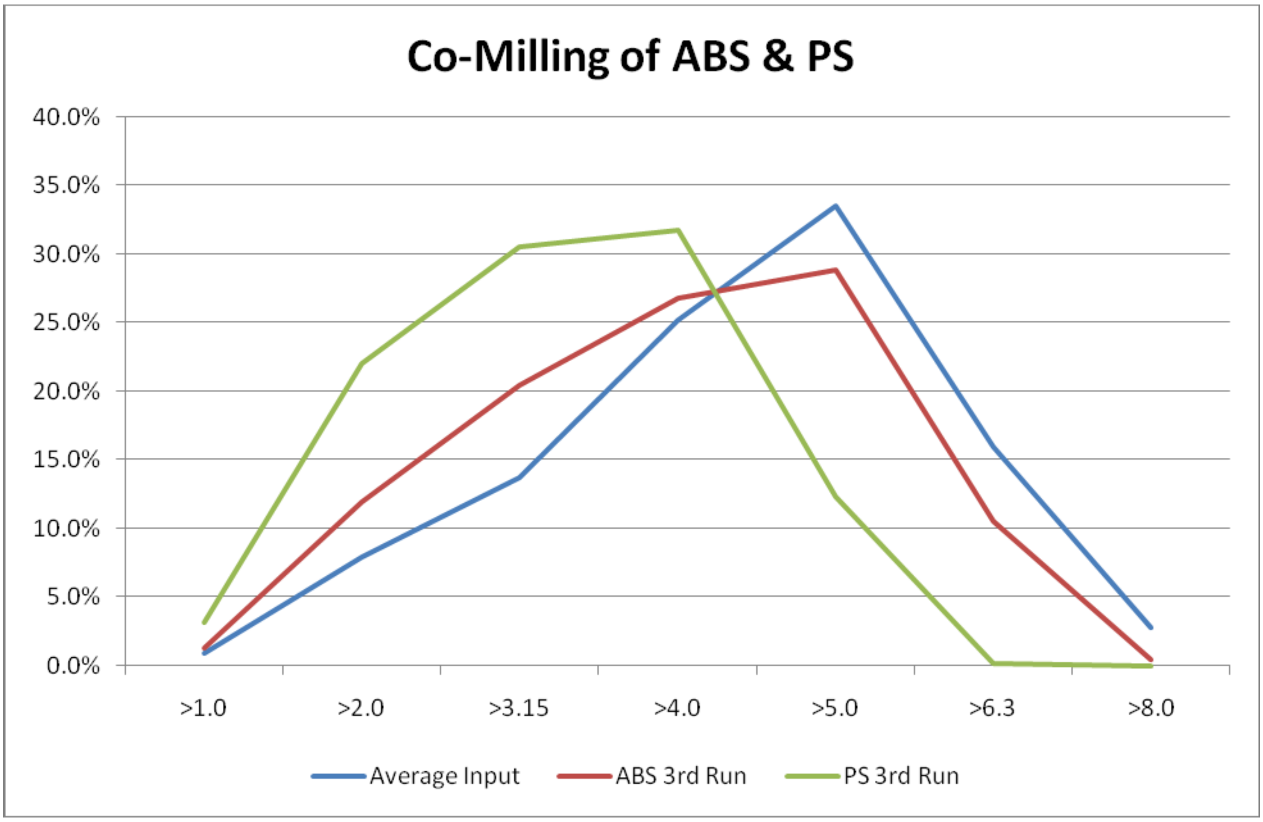
2.5.2 Co-milling of ABS and PP



A very marginal reduction in the numbers of particles above 6.3mm and a moderate increase in the finer particles were observed for the ABS/PP combination. That means that the mill was unable to generate any fundamental size reduction for this sample material.

However for the differential impact milling technique to be technically viable it is a prerequisite that one of the components fractures more readily than the other.

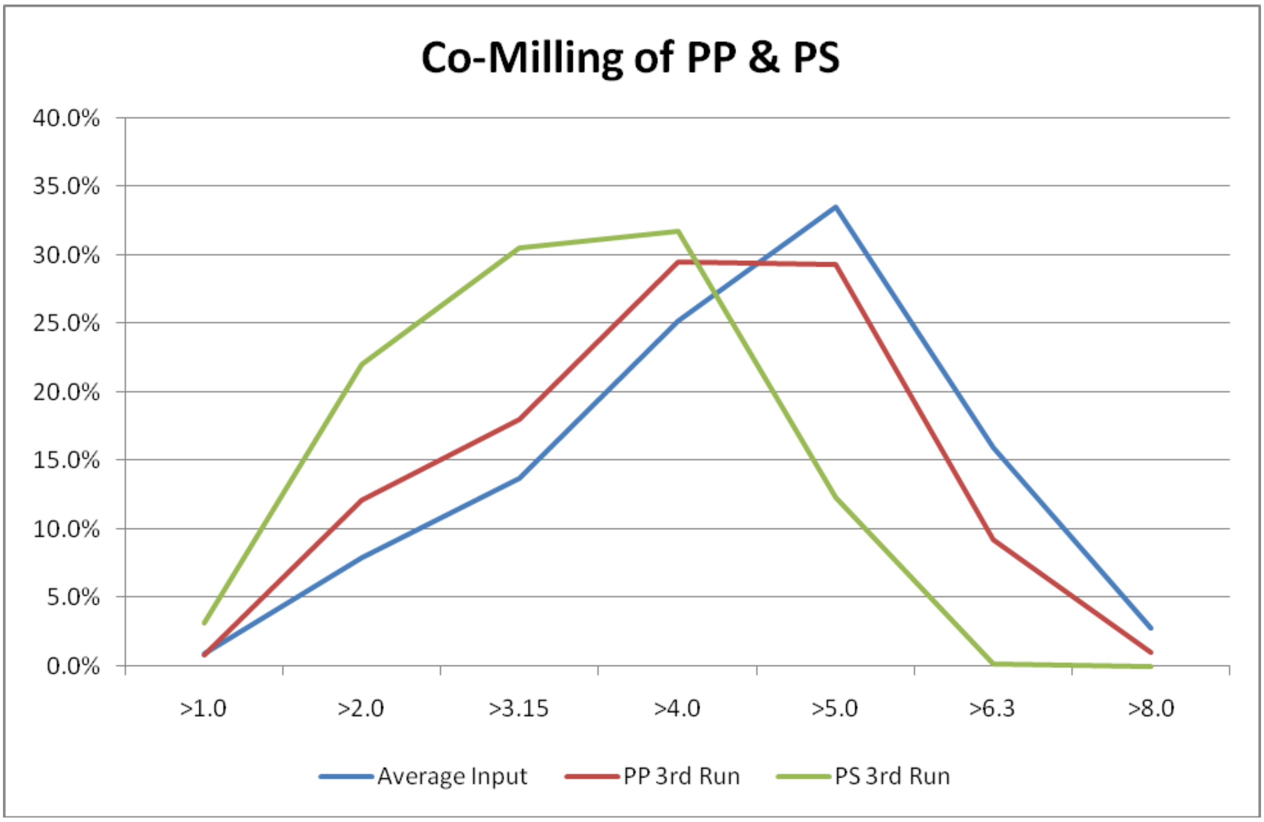
2.5.3 Co-milling of ABS and PS



As with the results above the ABS component was only marginally affected by the milling process. The PS component did however reduce in size, but the average particle size was only reduced by around 1mm.

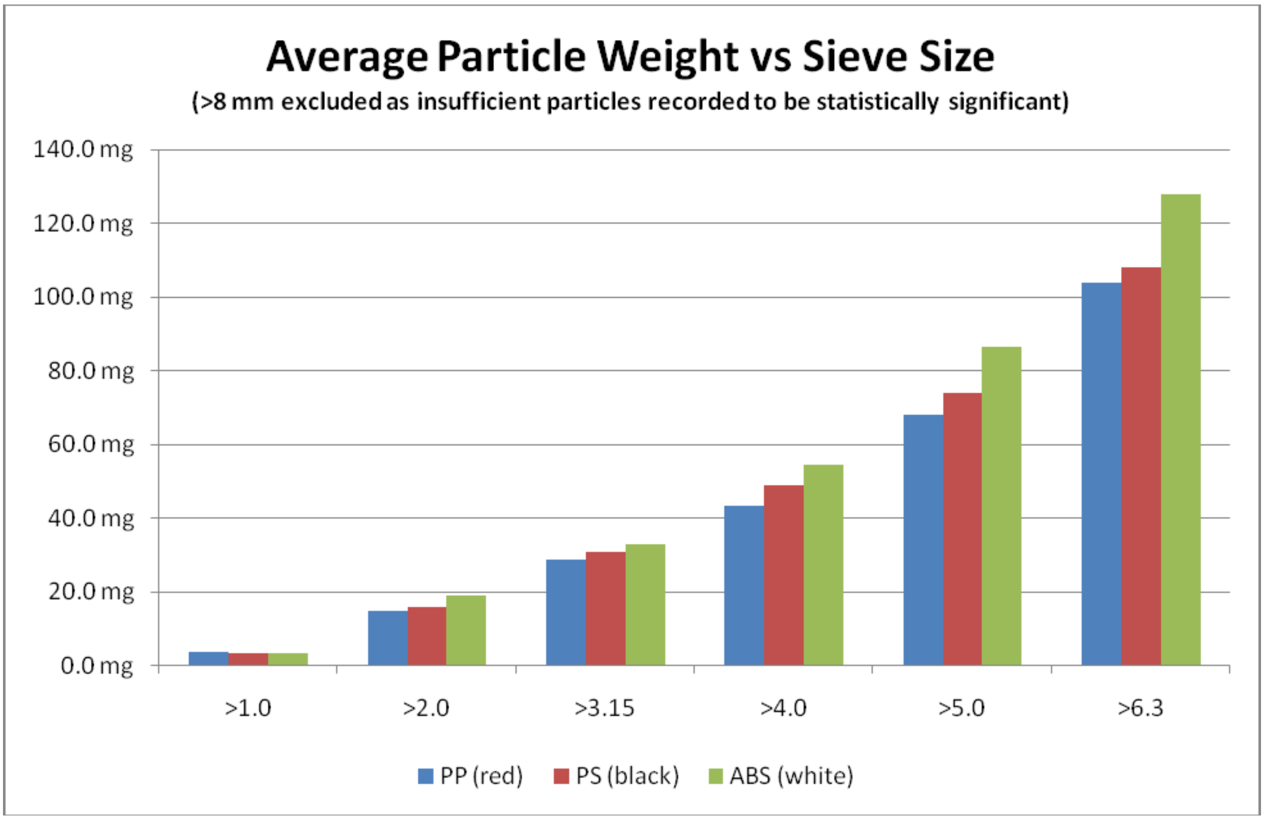
This illustrates that differential impact milling can occur, although the degree of separation achieved was limited.

2.5.4 Co-milling of PP and PS



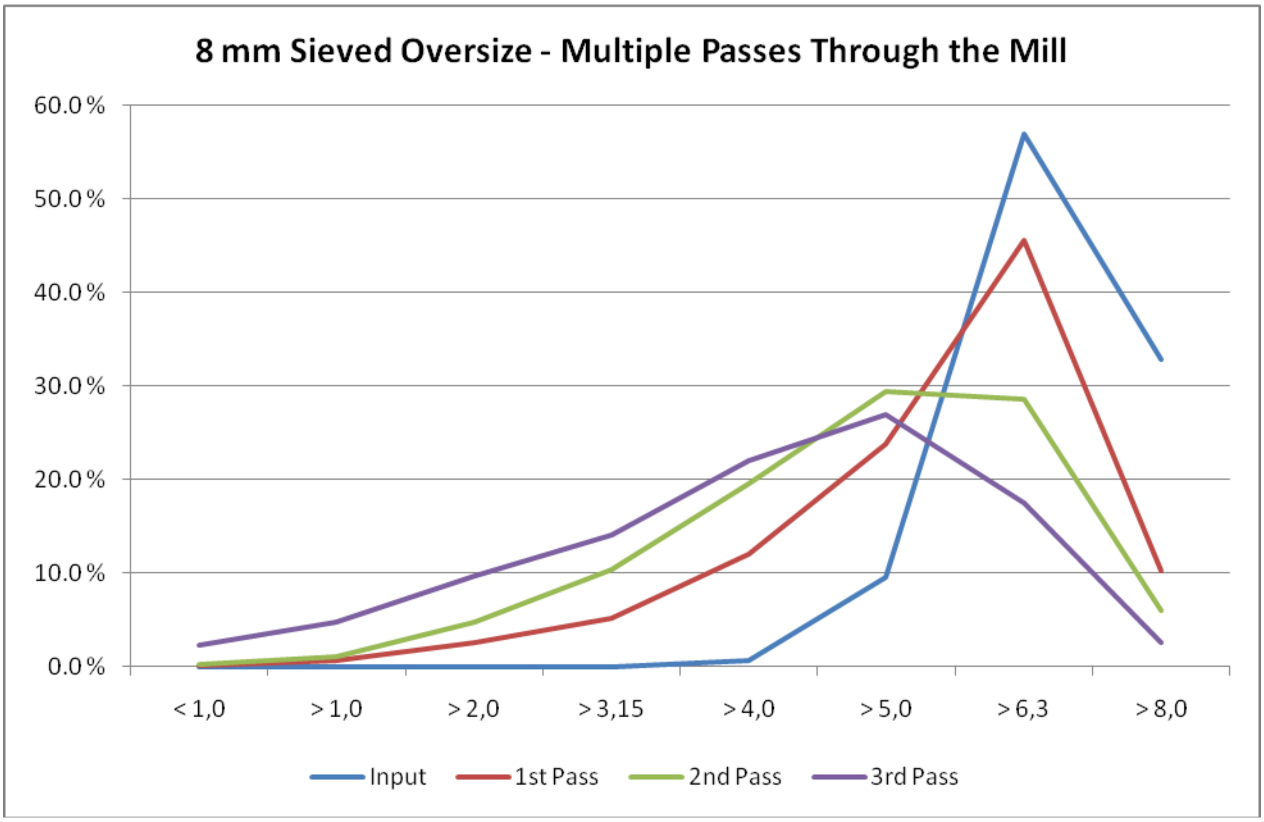
The results for this combination showed a limited degree of differential milling. The average size of the PS component reduced by about 2mm, while the ABS component reduced by about 1mm. Again this effect was not enough to allow a significant polymer separation by sieving the milled fractions.

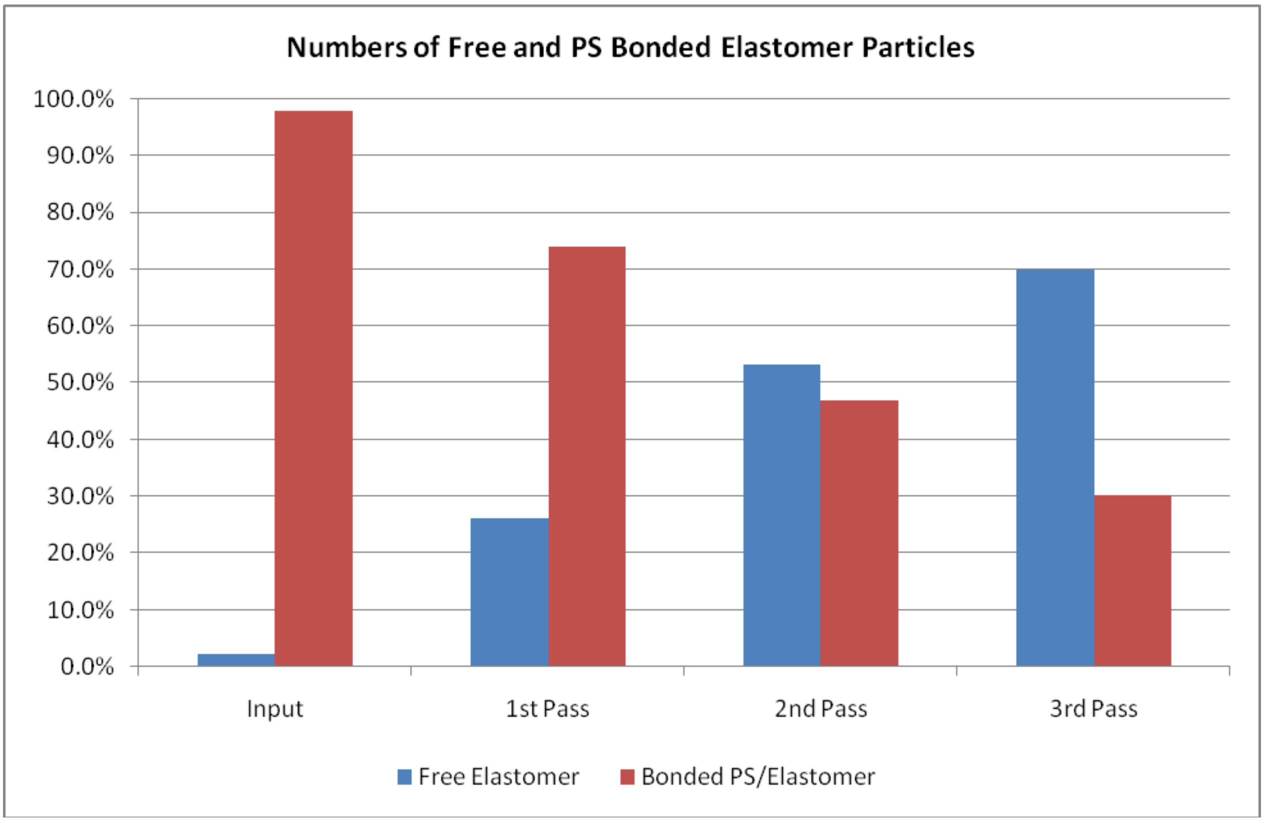
2.5.5 Average particle weight vs sieve size



Interestingly the average particle weight showed a trend that could not be explained by differences in polymer density. On average the ABS particles were heavier than the PS and PP particles, especially at the larger particle sizes. It may be that the samples exhibited marginal differences in the shape across the polymers selected. However in light of the overall poor milling performance, further investigation of the phenomenon was not considered appropriate.

2.5.6 8mm sieved PS/elastomer system





These results show that the mill reduced the size of large particles more effectively than smaller particles because the shape of the size distribution curve became flatter and skewed to the smaller size with each pass.

The graph comparing the number of free elastomer particles to the number of elastomer particles that were still bonded to a piece of PS after each pass, shows the mill's ability to delaminate the elastomer from the PS.

3.0 Conclusions

The results of the impact milling trial show that PS appears to be more brittle under the milling conditions applied than either the ABS or PP material, which showed similar levels of toughness. This means a partial separation of the PS/ABS and PS/PP into PS rich and PS poor fractions would be theoretically possible, however the current level of separation would not be commercially significant.

It was not possible to differentially size reduce the ABS/PP sample, since neither material was significantly affected by even multiple passes through the milling system. It appears that the principle limiting factor on the minimum size to which the mill could grind, is the impact energy rather than the number of impacts.

This would imply that the use of multi-ring rotor/stator combinations would not radically improve the level of size reduction achieved, since peak impact energies should be broadly similar despite higher numbers of impacts. Also it should be noted that whilst the Pallmann PXL18 did not show any signs of progressive temperature rise, larger mills would almost certainly take the outlet temperature of the polymers well above ambient temperatures, further increasing their toughness.

The trial did show that the mill was effective at size reducing feed material with a size above 6.3mm. It is therefore expected that the limited differential milling observed for PS would have been more pronounced for larger particle size input material. All the milling trials increased the level of fines, in both components, meaning that it would not be possible to recover two cleanly separated fractions from this process. It may be theoretically possible to sieve off the larger tougher input material as a pure polymer, but the finer fraction would always contain at least a degree of contamination of the tougher component.

The most useful effect seen in the milling trials was the ability of the mill to delaminate the elastomer from the PS for the coat-hanger samples. As part of an integrated process impact milling would enable specialist rubber removal techniques later in an overall process, to remove the rubber content far more effectively than from conventional granulator output product.