INNOVATIVE FILLER INJECTION SYSTEM FOR POWDERED RECYCLED URETHANE

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ABSTRACT

Cannon has developed the equipment to meter and mix a three-component slurry. High-solid-content slurry, obtained by blending ultrafine PU powder in non-catalysed Polyol as the carrier, is fed as a third stream at low-medium pressure to a mixing head via the axial port of the mixing chamber originally used for metering colour paste.

The recycling kit, dedicated dosing unit, and mixing head can be added to any existing high-pressure machine as a retrofit. This new technology not only gives to the producer the possibility to recycle pulverized PU; a number of solid fillers - such as graphite, melamine, alumina - can be fed and mixed into polyurethane "in line" as well. This paper describes the results of the trials held in Cannon Afros Lab on flexible moulded foam containing recycled PU powder, in cooperation with Mobius.

INTRODUCTION

Different ways exist to recycle PU foams. For flexible foams, the most commonly used one is "rebonding", which consists of first turning scrap foam into about 2 cm flakes, and then rebonding the flakes under pressure in a container using steam to cure a PU pre-polymer glue. The resulting products are used for a number of applications, the largest by far being carpet underlay. Carpet underlay represents over 400,000 ton/year in the largest market, which is the USA. However, end-user markets may be soon saturated for carpet underlay, resulting in lower demand for flexible scrap foams, and hence lower prices.

Chemical recycling methods do exist such as glycolysis to degrade rigid foams or other PU production wastes into new Polyol mixtures, but their use for flexible PU foam scrap (and especially for mixed wastes) is not practical and hence little used.

In the mid 90's a new technology was developed involving the pulverization of PU foams in two-roll mills at ambient temperature with sifting the resulting PU powder to obtain particle sizes of < 250 and preferably < 50 microns. The fine polyurethane powder, well dispersed into the Polyol, can be used for moulding using modified dosing machines that incorporate cylinder dosing units and hardened mixing heads and nozzles.

The impending laws about recycling in the automotive industry, and the availability of scrap PU foam that can be processed at reasonable costs, are catching the interest of moulded foam manufacturers regarding the possibility to use recycled foam in the production of new PU foam parts.

Cannon, world leader in polyurethane processing technology, has exploited its experience in setting up innovative injection processes for special applications to develop a kit suitable for a wide range of solid fillers. Mobius Technologies, Inc. is the leading supplier of equipment for processing scrap PU foam and has optimised the technology for producing high-quality recycled PU powder.

Cannon & Mobius joined their efforts in common lab trials to test the suitability of the axial injection process for solid fillers. Another goal was to demonstrate that an economically attractive percentage of recycled PU powder could be used in flexible moulded foam while maintaining industry performance specifications.

The results of those trials are most interesting for the flexible moulded foam manufacturers supplying moulded PU products to the automotive industry. In particular, recycled PU powder can be used in even higher percentages for the production of car-seat backs and head rests, where the requirements in terms of mechanical and physical properties of the foam are less demanding than in car-seat cushions.

SCRAP PU FOAM AVAILABILITY

It is likely that in the next decade the availability of scrap PU foam will be subject to very fundamental changes, caused by growing volumes of post-consumer foam and changing consumer preferences. For these reasons the possibility to recycle PU foam scrap will become more and more important in order to satisfy industrial production requirements and economic viability, and lead to sustainable development.

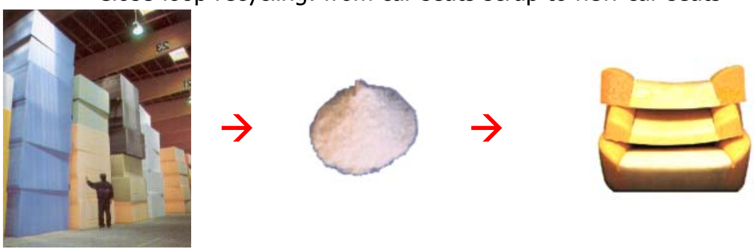
The number of end-of-life vehicles (ELV) reaching the dismantling and shredding companies each year is roughly estimated to be around 10 million in North America and also in Europe. While the United States is so far not coming up with specific legislation about recycling of ELV, the European Union approved in October 2000 directive 2000/53/EC, fixing to the automotive industry a precise schedule for recycling of the ELV's (see picture 1).

By January 2006, the reuse and recycling rate of ELV must reach 80% of the average weight of vehicles. By year 2015 this target is shifted to 85%. Considering an average ELV weight of 1150 kg and the average percentage of flexible moulded polyurethane foam in each car as 0.8%, the total amount of PU scrap from end-of-life vehicles should reach 184,000 tonnes per year, in North America and Europe together.

Picture 1 - Almost 10 million ELV's are waiting
to be recycled in North America and also in Europe

The recycling of flexible PU foam into powder can be closed-loop or open-loop type. Closed-loop recycling is when the recycled PU powder is used for the production of the same kind of pieces from which it has been generated (i.e. car seats scrap used only into new car seats). On the contrary open-loop recycling is, for example, recycling foam from car seats into other applications, such as slabstock flexible foam (picture 2).

Close-loop recycling: from car seats scrap to new car seats



Picture 2

Open-loop recycling: from slabstocks scrap to car seats

Which possible future evolution? Maybe in furniture applications?

If the goal is to maximize the amount of material recycled from a car, the best method may be to take the foam from car seats and recycle it into slabstock foam rather than into molded foam. This is because the amount of slabstock foam produced worldwide is much greater than the amount of molded foam. Also, the technology for incorporating recycled polyurethane powder into slabstock is already commercial and proven in slabstock.

If the goal is rather to maximize the amount of recycled material content in a car, then the best method may well be to use recycled polyurethane powder from slabstock scrap operations in the manufacture of new car seats. This is because there is a great deal of this clean material available on the market for rebonded foams. In either case, the best solution may not be closed-loop recycling in the strictest sense.

Scrap-foam recycling technologies may appear to be in competition with rebond applications, but this is not completely true. As higher supply of foam scrap pushes prices downward, taking some of that scrap out of the market via pulverization and incorporation back into foam production should help maintain good prices for PU scrap for rebonding, hence helping slab production economics.

Generally speaking, for all foam manufacturers, regardless of whether or not they are rebonders, the availability of inexpensive raw material for their foam plant can improve the foam manufacturing process economics. Therefore, both processes must be looked at separately with respect to recycling. Using some PU recycled content in manufacturing new foam is not incompatible with rebond operation, and in fact it may be complementary, since the two processes share several steps.

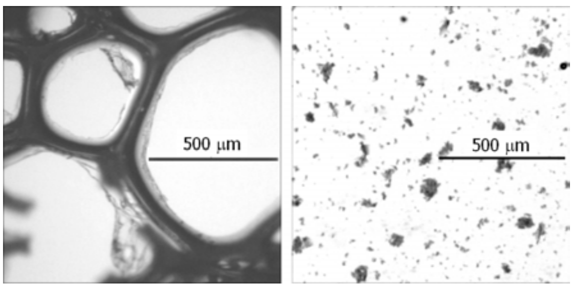
FROM SCRAP TO POWDER: THE MOBIUS TECHNOLOGY

In 1997 Mobius Technologies Inc. commercialised a polyurethane foam recycling process that grinds scraps of flexible foam to a fine powder, and reintroduces that powder as an additive in the production of new foam (picture 3). This can be done without any increase in the foam density; the filler takes up space in the junctions of the foam structure that would normally be made up of new polymer.

Picture 3 – Recycling Process: from the scrap to new flexible foam

This innovative technological solution, already demonstrated in the production of flexible foam for automotive, bedding, and furniture applications, has shown excellent results in terms of physical and mechanical properties of the resulting PU foams. Dedicated trials have also started with rigid foam.

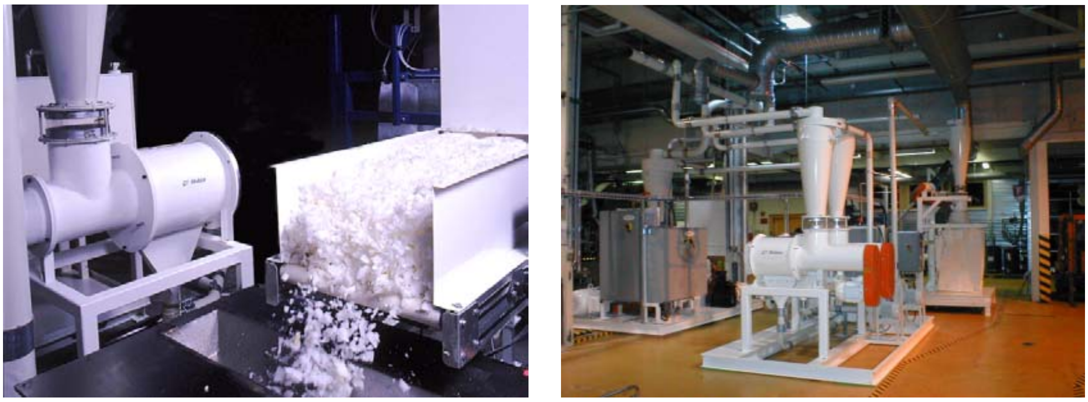
Mobius provides the equipment and the necessary process development to make available to the foam manufacturer a turnkey system for recycling scrap on site. The plant uses a non-cryogenic two-roll mill process in conjunction with proprietary powder-separation equipment specifically designed for polyurethane foam grinding. The flexible foam pieces are first ground to a size of about 10 mm, and then fed to a grinding plant that reduces the foam to powdered urethane with an average size of 50 microns (picture 4).



Picture 4 - Photomicrographs of the cell structure of a flexible foam and Powdered Urethane
Courtesy of Dow Europe Gmbh as part of the Mobius/Dow joint development agreement

Powdered urethane can then be blended into Polyol and used for the manufacture of new foams. The finer the PU powder, the lower the viscosity of the Polyol/PU powder blends. The plant is computer controlled so that only 1.5 operators are needed. Plants with continuous outputs from 100 kg/h to 1000 kg/h are available.

Yet, obtaining good foam powder is not enough: the process must have two additional properties in order to be sufficiently appealing. First, the process economics must be favourable. Then the process must be scaleable to avoid shipping lightweight foam to and from distant processing plant and to enable operation locally at the foaming plant or the waste source (picture 5).



Picture 5 – Mobius grinding and pulverisation plant

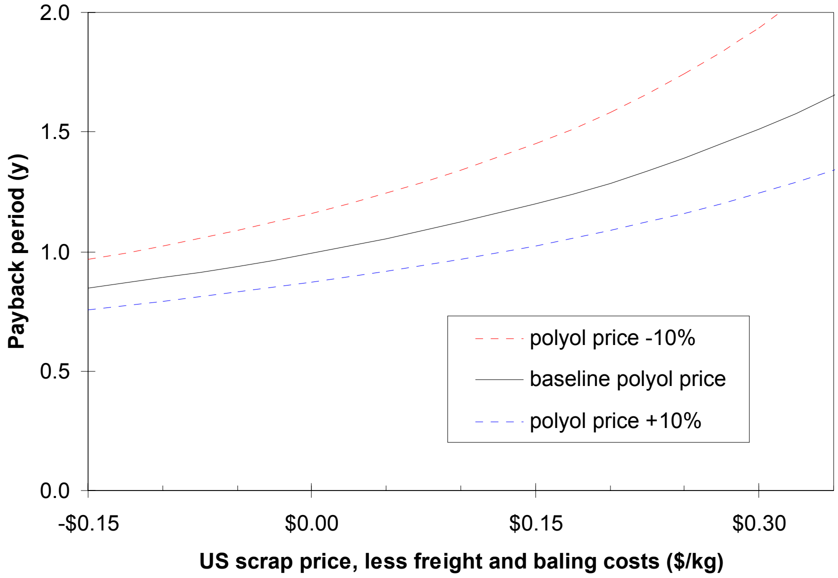
As shown in Table 1, the typical processing cost is around 0.13 €/kg for an averaged-sized operation running two shifts per day, to which royalties must be added. Once handling, baling, and shipping costs are deducted, the net value back to the slabstock foam producer of scrap foam in Europe today is about 0.30-0.35 €/kg. The total powder cost comes to 0.43-0.48 €/kg, plus royalties.

Table 1 - Calculation of Mobius operating costs

Mobius plant capacity (Kg powder/h)	225
Operating hours per year (2000 h = 1 shift)	4000
Number of operators	1.5
Operator salary ($/year)	25,000
Cost of electricity ($/kWh)	0.05
Electricity requirement (kWh/Kg powder)	0.5
Maintenance cost ($/year)	20,000
Annual Cost Breakdown ($/year)	
Labor	75,000
Utilities	22,500
Maintenance	20,000
Total	117,500
Powder Processing Cost ($/Kg)	
Total processing cost	0.13
Scrap value	0.30 - 0.35
Powder cost, not including license fees	0.43 - 0.48

Because the cost of the powder is significantly less than the cost of the chemicals it replaces, the foam producer can save money by replacing chemical with powder. Ten percent by weight of recycled PU powder can typically be used in new slabstock foam, without major changes in the foam formulation, resulting in substantial manufacturing cost savings.

Of course, cost savings are sensitive to a third factor, besides powder cost and powder level by weight in the new foam: the price of Polyols. In order to have a complete overview, a sensitivity plot can be used to determine the technology economics based on the variation of the three main parameters. Such a plot is shown in picture 6.



Picture 6 - Sensitivity plot showing variation of the cost savings with scrap-foam value and Polyol price at a level of 10% powder in a conventional slabstock foam (25 kg/m^3, 150 N).

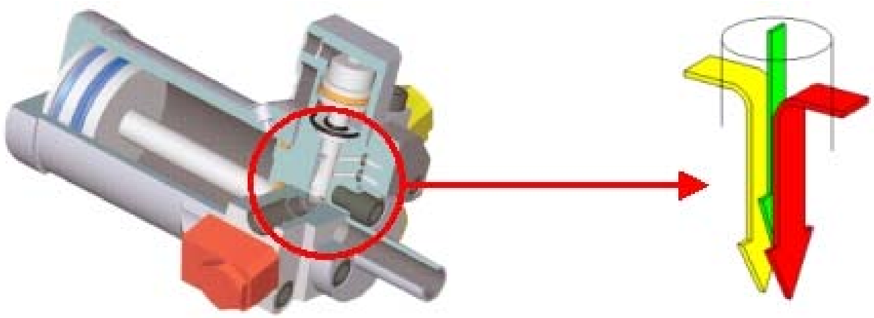
CANNON FILLER INJECTION SYSTEM

Cannon and Mobius have cooperated on ways to use recycled PU powder in new flexible moulded foam for automotive applications. While Mobius was focused on the pulverization and chemical reformulating aspects of the process, Cannon shared its knowledge and competence in polyurethane dosing, mixing and pouring technology. Moreover Cannon had the general target of developing a versatile injection system for filled materials. The development of an injection kit for filled components, versatile enough to be implemented on existing machines, could obtain the consensus of the automotive industry, as well as address the new regulations and demand in terms of recycling.

High-pressure machines processing filled Polyol suffer wear of mechanical parts such as piston pumps and injection nozzles. It is usually suggested to use filled raw materials only with machines equipped with metering cylinders and hardened nozzles. However, this kind of machine requires complicated and expensive solutions in order to fit the fast cycle time requested in the production of seats and head-rests for automotive applications.

Following the proven efficiency of the Cannon axial injection technology, already successfully implemented for mixing colour paste, and with the well-known AX multi-components mixing head, Cannon's engineers applied those concepts in designing the new filler injection system. Filled Polyol is injected in the mixing chamber along the pouring piston axis and, therefore, perpendicularly to the streams of the two main components.

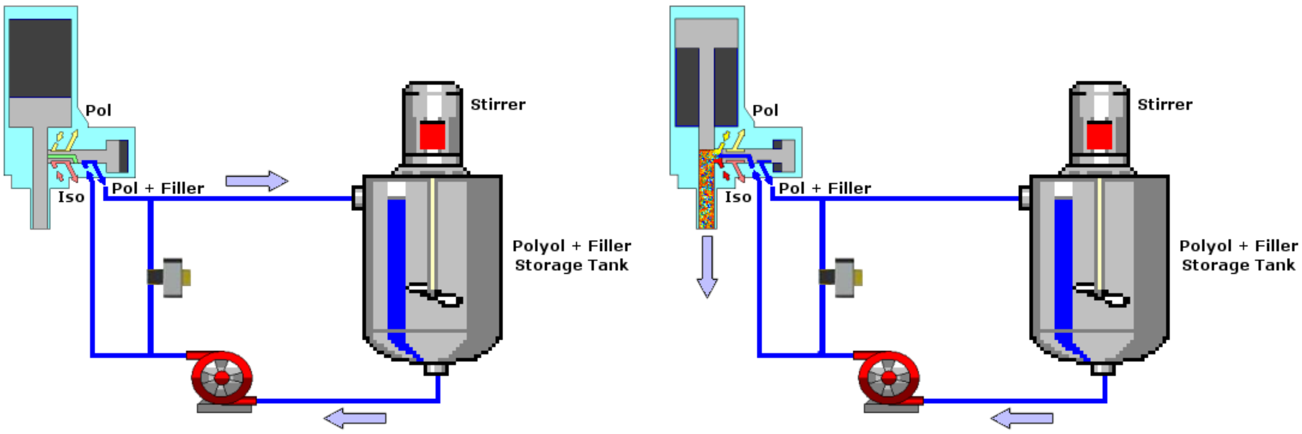
In this way the best mixing quality is achieved, even injecting the filled Polyol at pressures as low as 50÷100 bar. The mechanical energy for mixing comes from the impingement of the two main radial streams. When the pouring piston is closed, the filled Polyol is recycled through the mixing head.



Picture 7 - Cannon FPL /3 Mixing Head with High Efficiency Axial Components Mixing

This innovative kit avoids the use of metering cylinders and hardened nozzles. Furthermore the kit can be used on existing machines with minor modifications. The result of these research and design activities is a prototype filler injection kit built by Cannon for the joint lab trials with Mobius. The test was so successful and encouraging that Cannon has now started the engineering of a new kit suitable for industrial application. The prototype lab kit is composed of (picture 8):

- one storage tank with a stirrer, for Polyol blended with recycled PU powder (slurry)
- one pumping group for metering the slurry
- one screw flow transducer
- one Cannon FPL/3 for the axial injection of the filled Polyol, together with the usual radial injection of Polyol and Isocyanate (picture 7).



Picture 8 – Cannon prototype filler injection kit layout showing recycling and pouring phases

The stirrer in the tank has to properly keep in motion the whole mass of slurry in order to avoid separation between powder and Polyol, although when this happens, e.g. if the stirrer stopped over a weekend, the slurry is easy to re-homogenize.

Due to its high viscosity, the slurry gets warm during recycling through the mixing head. Therefore a properly dimensioned cooling circuit shall be foreseen, as well as the possibility to recycle the slurry at low pressure, outside the mixing head. The low pressure recycling also avoids stagnation of the slurry in the hoses from the metering pump to the mixing head. Stagnation in the hoses decreases the slurry temperature, resulting in higher viscosity, which gives pressure peaks when pouring is performed.

CANNON-MOBIUS LAB TRIALS

Two sessions of trials have been held in Cannon Afros Lab, Caronno Pertusella (Italy). Dow Chemical has been chosen to supply the raw materials: Polyols (Specflex® NC 632 and NC 700) and Isocyanate (Voranate® T-80). The recycled PU powder came from Mobius Technologies, Inc. The powder was mixed into polyol using a simple hand-held compressed air driven disperser. Cannon Afros supplied the mould and mould carrier with manual closing. The formulation used for the trials is described in Table 2.

Table 2 - Formulation for the Cannon-Mobius trials with the three-stream mixing head

		Stream # 3	***Stream # 1***	***Stream # 2***
	pphp	Slurry	Form. Polyol	TDI
	Formulation			
Polyol Specflex® NC 632	60	33.3	26.7	
Copolymer polyol Specflex® NC 700	30		30	
Mobius powder # 16 (assumes 1.5% water)	10	10		
Water (added to the blend)	3.365		3.365	
DEOA (100%)	1.0		1.0	
Glycerine	0.2		0.2	
Catalyst Dabco® 33 LV	0.25		0.25	
Catalyst Niax® A 400	0.1		0.1	
Catalyst Niax® A 300	0.25		0.25	
Surfactant Dabco® DC 5169	0.6		0.6	
Surfactant Tegostab® B 8715	0.5		0.5	
Isocyanate Voranate T-80 [Index=100]	43			43
Total	149.3	43.3	63	43
[Total water, pphp]	[3.67]			
Gas loss	9.0			
Foam weight (g)	140.3			
PU powder, % on total foam	**7.1**			
	Processing conditions			
Polyol & Isocyanates Temp (°C)	23			
Slurry temperature (°C)	30			
Polyol & Isocyanates pressure (bars)	150			
Slurry pressure (bars)	90			
Slurry output (g/sec)		106		
Formulated Polyol output (g/sec)			154	
TDI output (g/sec)				104
Total output (g/sec)	364			
Back-rest mold, filled epoxy, (21 litres) (°C)	60 (55)			
Release agent, Kluber 41-2013 (Kemi wax)				
Shot time (sec)	2.2			
	Reactivity characteristics			
Cream time (sec)	6			
Free-rise foam density (kg/m^3)	28			
Exit time (sec)	35			
Mold filling	Good			
Demold time > 5 minutes				
Demolding	Easy			
Foam cure	Good			
Part weight (g)	765			
Part overall density (kg/m^3)	36.4			

The formulation was fine-tuned by Mobius in order to keep the same overall final reactivity of the foam. With the addition of powder to the reaction components, the unit amount of heat and CO_2 generation is reduced. To increase heat generation and maintain the foam's original density, additional water and TDI are used. The powder also tends to soften the foam slightly, requiring small formulation adjustments to increase hardness. Generally, promoting cross linking through TDI index increase, by adding specific crosslinker, or by using a Dow VORALUX® low-solids polymer polyol, can enhance hardness.

The amount of recycled PU powder in the formulation was 7.1% on total foam weight, that is 10 pphp (parts per hundred Polyol). This amount provides a good balance between mechanical and physical properties of the foam and cost savings. Of course, more economic advantages can come from a higher percentage of recycle PU powder in the foam. This is possible particularly when the mechanical and physical requirements for the foam are not as tight as for car seats. For instance, headrests can definitely be foamed with a higher percentage of recycled PU powder.

After the trials in Cannon Afros Lab, the mechanical and physical properties of the foamed seats were tested by Dow Europe GmbH in Meyrin (Switzerland). Table 3 below shows the results of the tests.

Table 3 - Obtained Results - Mechanical and physical properties of moulded foams produced with the Cannon three-stream mixing head

Moulded seat foam samples		**#1**	**#2**	**#3**
[Index]		[95]	[100]	[95]
Part produced: seat back-rest				
Release agent used		Kemi	Kemi	Klüber
Mold temperature (°C)		55	55	60
Foam properties	***Test Method used***			
Overall part density (Kg/m^3)	ISO	36.5	36.5	36.5
Hardness IFD 40% (N)	ISO 2439-97	237	248	211
SAG Factor, IFD 65/25	"	4.6	4.8	4.3
Foam core density (Kg/m^3)	ISO 3386-98	36.5	36.5	36.4
Hardness, CFD 40% (kPa)	"	6.2	6.3	5.6
Hysteresis loss (%)	"	29.2	29.5	24.6
Mechanical strength				
Elongation (%)	Ford 416-4/89	85	83	85
Tensile strength (kPa)	"	115	131	117
Tear strength (N/m)	ISO 8067-89	356	314	332
Resilience (%)	ASTM	51.5	50	59
Compression sets				
Compression set, 50% CT (%)	Ford/ISO 1856-80	9.0	8.8	7.2
Compression set, 75% CT (%)	"	9.7	11.0	7.9
Heat ageing	ISO 2440-97			
Height loss (%)	"	0.4	0.3	0.7
CFD 40%, Force loss (%)	"	16.7	21.1	13.8
Humid ageing	ISO 2440-97			
Height loss (%)	"	1.0	0.8	0.4
CFD 40%, Force loss (%)	"	9.9	5.1	7.2
Compression set, 50% CT (%)	"	21.5	24.7	16.9
Compression set, 75% CT (%)	"	39.4	42.8	25.4
Dynamic Fatigue	ISO 2439-97(10mn)			
Height loss (%)	"	7.2	10.4	
IFD 40%, Force loss (%)	"	33.4	38.4	

Sample #3, processed at a higher mould temperature and with a different type of releasing agent, gives the best results for all the key parameters: higher resilience, lower hysteresis loss, lower compression sets and better resistance to heat and humidity ageing.

FUTURE STEPS

After the success of the joint trials with Mobius, Cannon has started a second phase of the project, with three main targets:

1) Test the injection kit with fillers different from recycled PU powder, for example alumina, melamine, graphite, etc.
2) Test the same injection kit with different kind of foams, mainly filled rigid foam. In picture 9, it is showed samples of rigid foams produced with different percentages of graphite. This filler is utilized to improve the flame retardant properties of the foam, which can be suitable for special insulation applications such as in the aeronautics industry and buildings.
3) Set up a filler injection kit suitable for heavy-duty production, to be proposed to the automotive market, as a device to be implemented on new or existing machines.

Picture 9 – Samples of rigid foams realized during the held trials in Cannon Afros Lab

Pure PU

PU + 5% Graphite

PU + 45% Graphite

CONCLUSIONS

The results obtained show that recycled PU powder can be used in moulded car seats at levels of up to 7% on the overall foam weight. Mobius selected this level as it was demonstrated in earlier trials that at such a level, the mechanical and physical properties of the moulded foam parts were not significantly affected and seat foams were still meeting the specific OEM specifications for car seats.

The prototype of the Cannon Filler Injection Kit with the axial injection of the slurry has proven to give excellent results in terms of mixing quality. The kit is very attractive for polyurethane foam manufacturers because it can be added easily to any machine, new or existing. The process is also very promising because it allows the use of recycled PU powder at fast cycle times while avoiding wear problems. This removes barriers to the closed-loop recycling of foam from ELV's.

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BIOGRAPHIES

Stefano Andreolli – was born in Milan (Italy) in 1970. He got a degree in Aeronautical Engineering at Politecnico of Milan, with specialization in aerospace systems.
He worked for one year in a company for wireless communication products and joined Cannon Afros in 1999, as sales engineer for Far East markets. Since summer 2002, he is product specialist for automotive seating technology.

Christian Cairati – born in Milan, Italy, in 1970 – has technical education in Information Technology with few specialisations in Plastics Technologies and a Master in Quality System Management. He worked for ten years in processing companies as production manager and for four years as technical, quality and marketing consultant for the Italian Association of Plastic Processing Machinery Manufacturers - Assocomaplast.
He joined Cannon Afros in 2001, as Company Communication Manager.

Paul Berthevas - graduated from the "Ecole Nationale Supérieure de Chimie de Paris", in 1968. He worked for the past 28 years on Polyurethane Chemistries and Application Technologies and contributed to the development of Copolymer Polyols and their use in flexible polyurethane foams and co-authored a number of papers on the subject. He also developed chemistries and application technologies for the production of knife coatable, heat curable microcellular polyurethane frothed foams and holds patents on this application technology.
He then became Global Technology Manager at Dow Chemical with responsibility for molded polyurethane foams and Senior Development Associate responsible for the flexible foam recycling project. Today, he is working as Senior Consultant for Mobius Technologies, located in Meyrin / Geneva, Switzerland.

Robert Villwock – received a B.S.E. in Polymer Science and Engineering from Case Western Reserve University and a Ph.D. in Chemical Engineering from the University of California at Berkeley. As a Research Engineer for The Dow Chemical Company, he contributed to the research and development of new thermoplastics, including styrene terpolymer foams, polyethylenes, and recycled plastics. He was a key part of the Applied Plastics and Materials R&D group, which launched Dow's first effort into plastics-recycling R&D in 1989. Since 1999, he has been Director of Polymer Engineering with Mobius Technologies, Inc.