EPC Promises Castings Never Before Possible

In addition to all the benefits already mentioned, EPC holds even greater promise for the ferrous foundry industry because it allows parts to be cast which were only castable before by the far more expensive investment and lost wax methods.

As a result, today's engineers can design parts with increasing complexity; parts with thinner walls, blind holes, multiple convoluted passages, and strict dimensional precision requirements that traditional casting methods were unable to produce. Any part which can be molded in foam can now be precisely and economically cast in metal using the EPC process.

Frequently, this new level of design freedom results in a single cast part rather than several that must be assembled. When this is possible, the savings and efficiencies are even more dramatic. Indeed, the potential to cast more sophisticated parts enables foundries to compete for projects that would never have been feasible before.

A "Breakthrough" Technology That's Over Twenty Years Old

This brochure will introduce you to poly-(methyl methacrylate) (PMMA) foam pattern material from Dow. But to fully appreciate what PMMA means to the ferrous foundry industry, let's take a quick look at why Evaporative Pattern Casting (EPC), also known as Lost Foam Casting, was considered a breakthrough technology when it was introduced over 20 years ago.

In the EPC process, a foam pattern is produced by molding pre-expanded foam beads in a heated die. The patterns are dimensionally precise, and may be quite complex. They are assembled into a cluster, coated with a refractory slurry, dried, and surrounded by unbonded sand in a flask. Molten metal is poured into the coated pattern and displaces the foam, precisely replicating the pattern.

The EPC method is ideally suited for repetitive high-volume castings of complex parts. And because the EPC process produces near-net shapes, foundries have reduced many costs related to part manufacture. Here's a quick review.

MINIMAL OR NO MACHINING COSTS. A complex part cast in green sand would normally require extensive machining to remove flashing and to achieve the desired dimensional precision. The same part, cast with EPC, can be produced at very near net shape, thereby significantly reducing or eliminating the amount of machining necessary.

REDUCED MOLD AND CORE COSTS. In EPC, the foam pattern is a positive rather than a negative image of the part. In contrast to the conventional wooden patterns used in sand casting, the aluminum molds used to make foam patterns have a very long life. Therefore, many problems and attendant costs associated with molding green sand are eliminated with the EPC method.

MINIMUM RISER REQUIREMENTS. Risers, which are sometimes used to trap gases, slag, or other impurities that get entrained in the metal, are often unnecessary when casting using the EPC method and PMMA foam patterns.

LOWER SCRAP RATES. EPC-cast parts can have a smoother surface, with less flashing, internal voids, and other defects than their green-sand counterparts. This, combined with the reduction in core-shift problems, usually leads EPC foundries to reduced scrap rates.

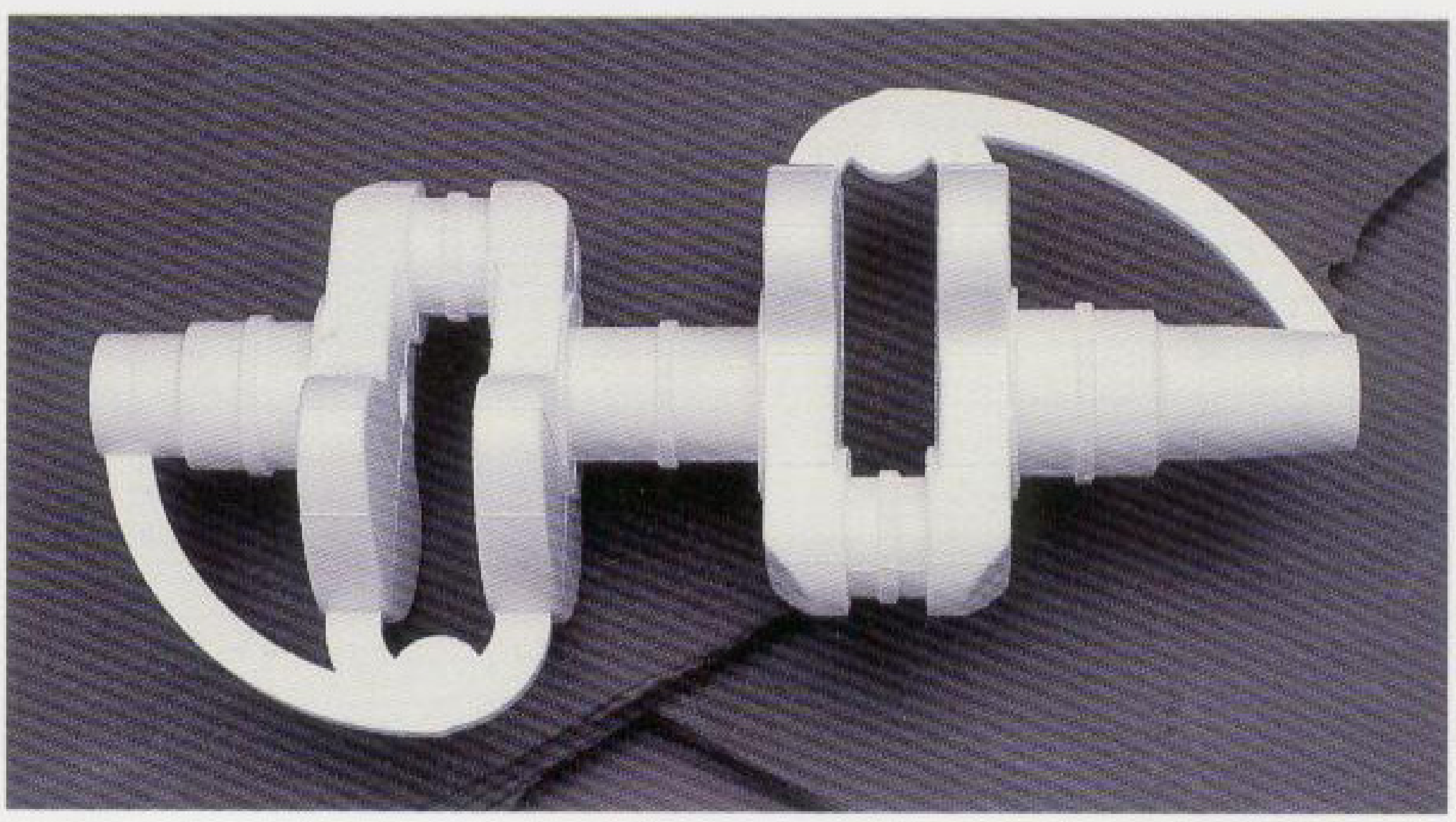
LOWER MATERIAL COSTS. The EPC method can require less metal per part because there is less need to cast an oversize part to compensate for an inability to achieve dimensional precision. In addition, use of the EPC method allows clustering of patterns and higher pouring efficiencies, thus offering even greater reductions in material costs.

REDUCED ENERGY, LABOR, AND MAINTENANCE COSTS. These cost reductions follow from the benefits mentioned above. Less energy is required because less metal is required. Similarly, labor and maintenance costs can be reduced because EPC patterns can be less expensive and are less cumbersome, and because less capital is required to use EPC technology.

PRODUCTIVITY GAINS THROUGH PART CLUSTERING. EPC promises substantial productivity gains because it offers the freedom to cluster many parts per flask.

In summary, since its introduction over 20 years ago, EPC technology has offered significant promises: parts cast at very nearly net shape without the use of cores, resulting in increased productivity and numerous cost efficiencies.

Until recently, however, something has hindered EPC from fulfilling these promises in ferrous casting. Let's consider this problem, and its solution: PMMA expandable beads from Dow.



This PMMA foam pattern for casting a crankshaft illustrates the complexity of parts that can be produced with near-net dimensions and surface quality.

One Major Obstacle: Carbon Residue

Although the ferrous foundry industry has long acknowledged the potential advantages of EPC over other casting methods, one obstacle has stood in the way of its complete acceptance. That obstacle is lustrous carbon defects, which are frequently encountered in ferrous castings poured with patterns made with the original EPC foam, expandable polystyrene (EPS).

When polystyrene decomposes in the presence of molten metal, a large amount of carbon residue is produced. This residue remains in the cavity, displacing the iron or steel in the mold, and may cause a poor reproduction of part surfaces as well as serious internal defects. These parts may be unacceptable in appearance and may lack structural integrity. As a result, much of the cost efficiency promised by EPC has never been realized.

In 'high-performance' applications – those in which ductile iron or steel cast parts must endure dynamic stress (cyclical strain or repeated flexing in use) – lustrous carbon defects on the surface, or in the interior of the casting, can lead to potentially catastrophic fatigue failures.

The Solution: Poly(methyl methacrylate) (PMMA) Pattern Foam Material

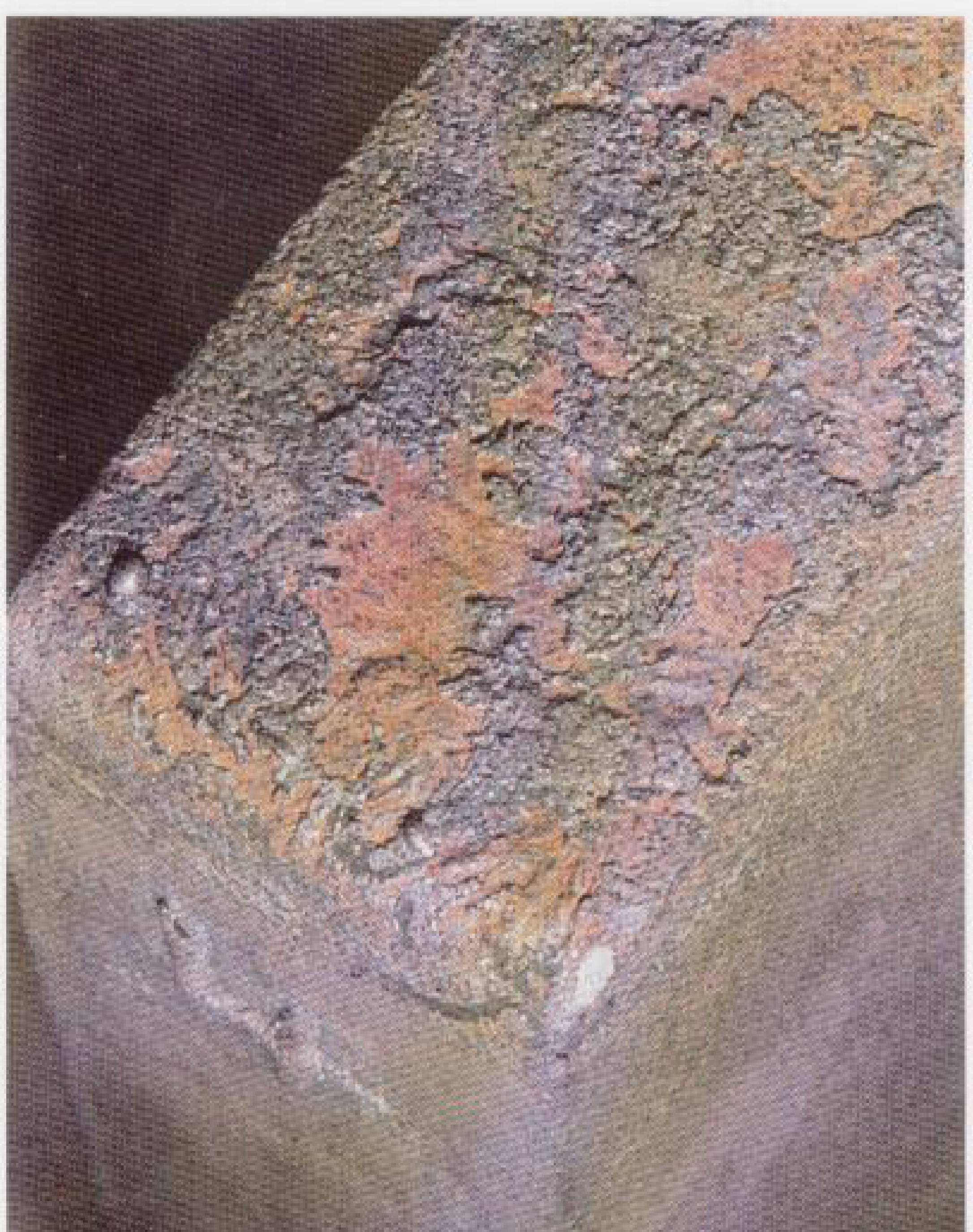
This last barrier to EPC acceptance has finally been removed with PMMA, an alternative pattern foam material which dramatically reduces carbon defects.

The two photographs below show the dramatic reduction in carbon residue when a part is cast using PMMA pattern foam. Each casting was poured with nodular iron using 2″ (50 mm) thick by 8″ (200 mm) square foam test blocks. The densities of the foam patterns were in the 1.4 to 1.7 pcf (22 to 27 g/l) range. The blocks were cast under identical conditions – coated with the same refractories, oriented vertically, and gated at the bottom and mid point of one side.

Polystyrene, on the left, shows extensive carbon defects on the sides and upper casting surface. PMMA, on the right, demonstrates a complete absence of any carbon defect. Additional tests have confirmed the ability of PMMA to reduce carbon defects even in shapes where polystyrene is a complete failure.

It is perhaps a bit puzzling that these foams, both of which contain carbon, behave so differently in the casting process. Polystyrene has an inherent problem with lustrous carbon defects, while PMMA significantly reduces them. This is due to the different chemical compositions of the two foams. Let's take a close look at these differences and find out exactly how PMMA is able to reduce carbon defects so dramatically.

Historically, carbon defects have been a concern when casting bulky parts with polystyrene patterns. PMMA overcomes this concern as illustrated by this pattern for a 90 lb (41 kg) wheel hub. Quality parts are achieved even though this part includes a 2″ (51 mm) thick, centrally located cross-section. Void free ductile iron castings, in commercial production with this pattern, require no risering.



Casting from polystyrene pattern

Casting from PMMA pattern

Molecular Structures of PMMA and Polystyrene.

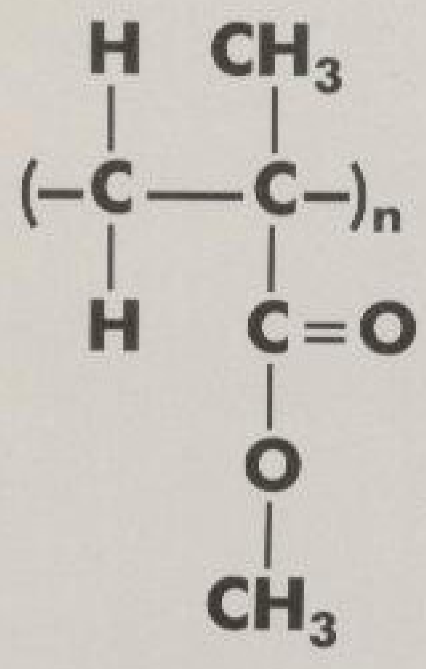


Figure 1. Molecular Structure of PMMA – poly(methyl methacrylate)

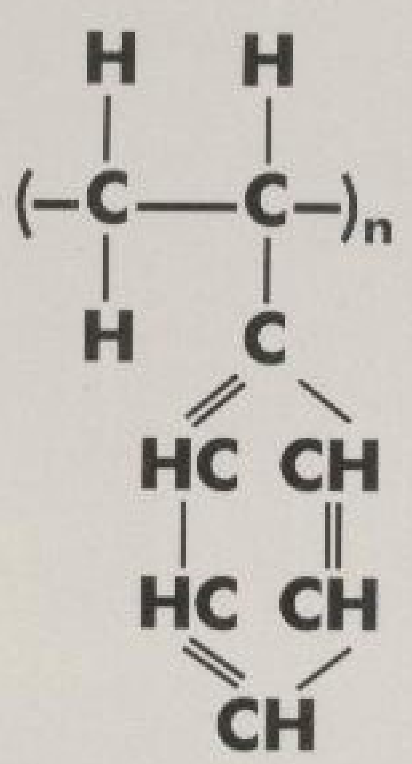


Figure 2. Molecular Structure of Polystyrene

PMMA Contains Fewer Carbon Atoms

Figures 1 and 2 are molecular models of poly(methyl methacrylate) and polystyrene. A quick atom count shows 5 carbon atoms in the PMMA monomer, and 8 in the polystyrene monomer unit.

One might conclude that the lesser amount of available carbon in PMMA would reduce the amount of carbon residue in a casting by a substantial ratio of 5:8. Yet the actual reduction of carbon deposits is much higher due to the different ways polystyrene and PMMA decompose.

Oxygen in PMMA Carries Away Carbon

Note that PMMA contains atoms of oxygen, while polystyrene does not. These oxygen atoms contribute to the decrease of carbon residue by helping to carry away some of the carbon from the mold cavity.

At the temperatures achieved in ferrous casting, oxygen typically escapes from the pattern area as CO, carbon monoxide. Thus, each oxygen atom scavenges a carbon atom from the polymer molecule.

Thermodynamic Instability Leads to Rapid Decomposition of PMMA

The polystyrene molecule contains a carbon-rich structure called a benzene ring which is highly stable, and very difficult to thermally decompose.

Even when benzene does decompose, there is still a strong tendency for carbon to be formed along with hydrogen gas. The much lower yield of carbon formed when PMMA decomposes may in part be due to the absence of benzene rings in its structure.

Gases vs. Liquids: Different Methods of Decomposition

The third reason PMMA foam produces less carbon residue is related to the mechanism of its decomposition. PMMA decomposes by a rapid "unzipping" method. The products of such decomposition are predominantly gases which rapidly escape from the pattern area.

Polystyrene, on the other hand, decomposes by a slower, random cleavage process which produces large amounts of liquids. These liquids are exposed to the molten metal for longer times, increasing their chance of being trapped in the cavity. These residues are sometimes observed as sticky viscous masses in used sand and may pose a problem in sand reuse. Other than a small accumulation of black "soot," sand used for evaporative casting with PMMA remains clean and free-flowing.

Does Theory Become Reality?

Theoretically, casting with PMMA patterns should result in dramatic reductions in carbon residue. Lab and field evidence support this theory.

Tables 1 and 2 show results of sophisticated laboratory tests performed at Dow to measure the amount of carbon residue left after heating foam samples to ferrous casting temperatures. As seen in Table 1, whether the foam pattern is heated at a slow or fast rate, the yield of residue is greatly reduced when PMMA is used.

Even more significant than this lab data are the successes of various foundries in reducing carbon defects in grey and ductile iron parts including hubs, disc brake rotors, valves, and many others.

Table 1. Pyrolysis Residue Yields

Polymer	% Residue	
EPS	6.2	15.1
PMMA	0.8	3.2
Conditions:		
Heating rate to 1400°C (2550°F)	1°C/sec. (1.8°F/sec.)	700°C/sec. (1260°F/sec.)
Hold at Max. Temp.	6.7 min.	18 sec.
Atmosphere (no flow)	Air	Nitrogen

Table 1. A sample of each polymer was weighed into a quartz capillary tube and heated in a nitrogen or air atmosphere by a platinum resistance coil to 1400°C (2550°F) at a predetermined rate. The maximum heating rate, about 700°C/sec. (1260°F/sec.), attempts to simulate the thermal history experienced by foam in the EPC process.

Table 2. Carbon Pickup in Low Carbon Alloys

With EPS at 1.2-1.6 pcf (19-26 g/l)	0.1 to 0.3%
With PMMA at 1.2-1.5 pcf (19-24 g/l)	0.05%

Steel castings made with PMMA patterns have exhibited carbon pickups of less than 0.05% maximum. Compare this with the carbon pickup of castings poured from the same alloy with polystyrene patterns – between 0.1 and 0.3%.

Increased Productivity with PMMA

EPC casting with PMMA patterns can lead to increased foundry productivity. By virtually eliminating carbon defects, one can fit more parts per flask, without engaging in prolonged trial and error studies of coatings, gating schemes, or pattern orientations.

The above data shows that using PMMA significantly reduces carbon defects in iron leading to higher quality parts and significant cost reductions. Near net shape cast parts mean lower machining costs and scrap rates.

And PMMA offers many other benefits – benefits to the designer, the foundry, the foam pattern molder, and the machine shop alike. Let's look at some of them.

PMMA is Moldable on the Same Equipment as Polystyrene

No additional capital expense is required to mold PMMA patterns. Its pre-expansion and molding properties allow it to be processed on the same equipment now used to mold polystyrene.

Wider Density Range Means PMMA is More Forgiving

PMMA also holds a molding advantage over polystyrene because it allows a wider density range. Although polystyrene parts can be molded from 1.2 to 3+ lbs/cu. ft. (19 to 48+ g/l), it is typically molded at the low end – between 1.25 and 1.35 lbs/cu. ft. (20 and 22 g/l) in an attempt to avoid carbon defects. Because PMMA virtually eliminates the carbon problem, it can be used at densities higher than 1.3 pcf, if desired. This means the foundry can consider factors other than carbon generation before selecting the desired pattern density. PMMA patterns have been used at densities between 1.3 and 2.0 pcf (21 and 32 g/l).

PMMA Offers Even More Design Flexibility

In the same way that EPC offers design flexibility advantages over green sand casting, PMMA offers design advantages over polystyrene. PMMA beads are available in two mesh sizes, one smaller than the typically used polystyrene beads. Small mesh PMMA beads offer excellent edge definition and fill. Thin-walled parts, like the swage sleeve shown on this page, can be molded with PMMA. This means you can specify patterns with confidence and take advantage of the lower rejection rates for finished castings.

Rapid Dimensional Stability and Long Shelf Life with PMMA

Because PMMA has excellent barrier properties, it retains its blowing agent for a long time. This means that following molding, PMMA patterns are dimensionally stable sooner, and prolonged aging is unnecessary. Unexpanded PMMA resin has a shelf life typically greater than six months, while pre-expanded beads remain useful for up to three months. By contrast, pre-expanded polystyrene beads must be used immediately because they readily give up their blowing agent. This can result in lower pattern costs given the economics of longer foam molding runs, less wasted resin, and greater molding scheduling flexibility.

PMMA is Resilient

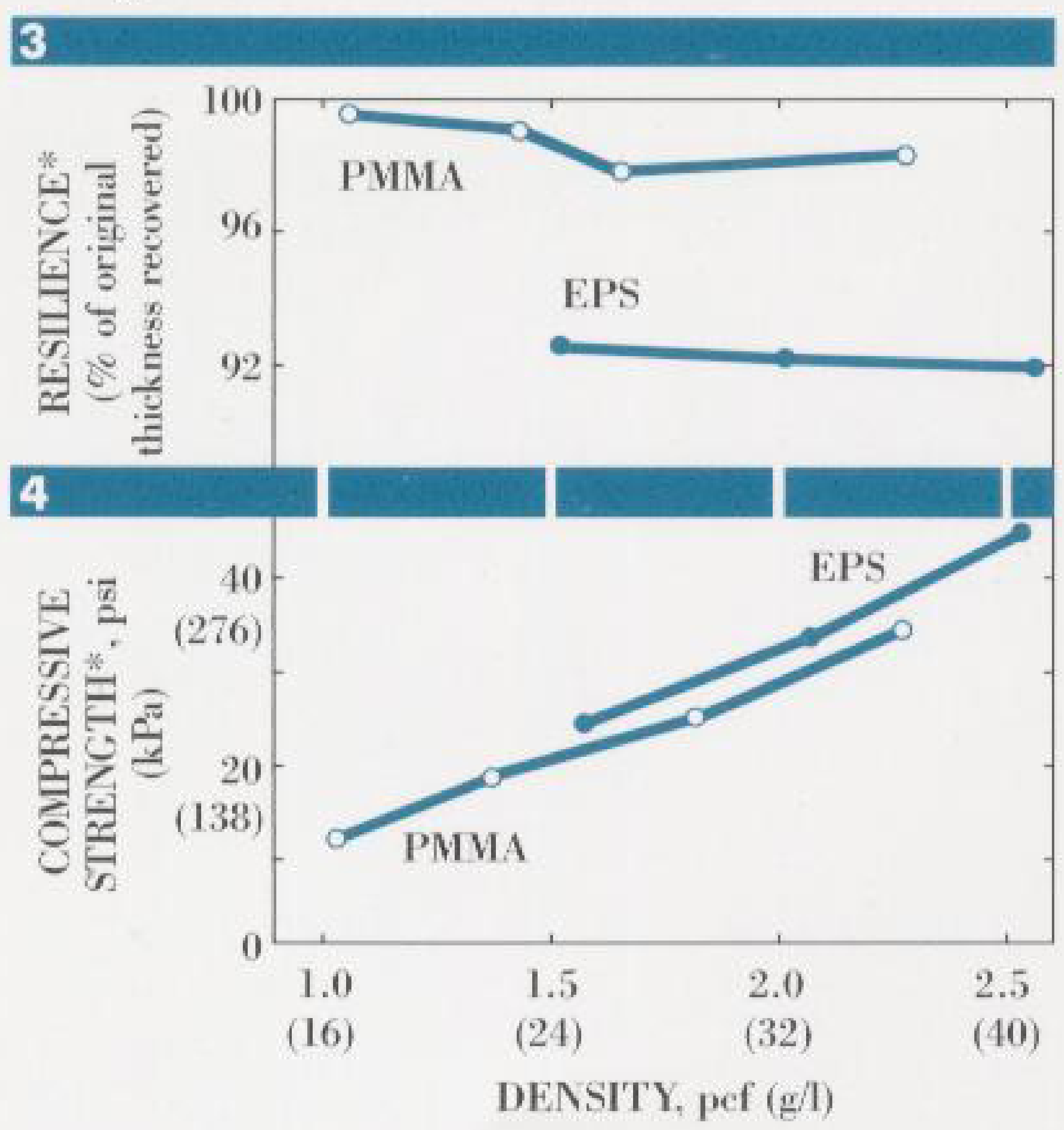
Compressive strength of PMMA and polystyrene is density-dependent. Figure 4 below shows that at 15% compression, the restoring forces for the two materials are similar, although polystyrene offers somewhat greater strength. Polystyrene also offers greater flexural and tensile strength properties.

But also important is the measurement of resilience. Resilience is a measure of a foam's ability to return to its initial shape after a deforming force is removed. Following a compression to 85% of original thickness, Figure 3 shows that the recovery of polystyrene is only 92%, compared to 98% for PMMA. This resilience minimizes permanent damage to foam patterns due to handling mishaps.

In summary, PMMA foam patterns provide greatly reduced carbon residue in ferrous parts cast using the EPC method. In addition, it offers many other important properties like resiliency, increased moldability, long shelf life, and rapid stabilization. In short, PMMA foam overcomes the obstacles to gaining the promised advantages of EPC.

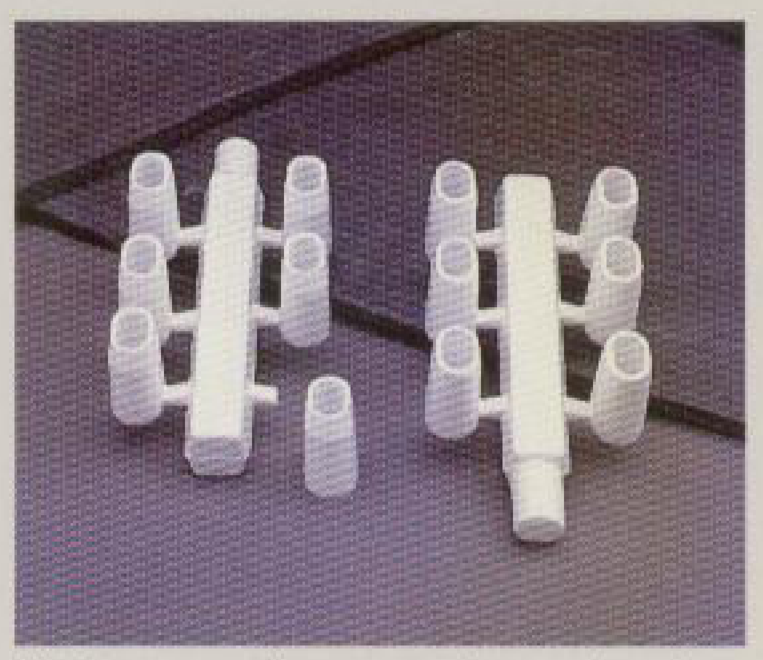
But of course, EPC is still a technology foreign to many foundries, and capitalizing on its advantages may seem to be a difficult task without adequate technical assistance. Let's look at some of the ways Dow is capable of making your transition to EPC a smooth one.

Figures 3 and 4. Resilience and compressive strength of Foam Pattern Materials



*Measured for compression to 85% of original thickness.

Figures 3 and 4 demonstrate that both polystyrene and PMMA have the strength to withstand normal compressive load-bearing pressures. But PMMA is far more resilient. Compressed to 85% of original thickness, polystyrene recovers to only 92% of its original thickness, compared to at least 98% for PMMA.



This pattern for swage sleeves also demonstrates the ability of PMMA to fill thin-walled sections. Wall thickness is just 0.080" (2 mm).