SAE TECHNICAL PAPER SERIES

981005

New Binder for Casting Cores: An Industrial Application to Safety Suspension Parts

Andrea Ferrero and Marcello Badiali
Teksid Aluminum Foundry

Richard Schreck and June-sang Siak
General Motors Research and Development Center

William Whited
GM Powertrain Group

Reprinted From: Product and Process Integration: Advanced Technology (SP-1337)

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL

International Congress and Exposition
Detroit, Michigan
February 23-26,1998

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (412) 776-4841 Fax: (412) 776-5760

ISSN 0148-7191

Printed in USA

981005

New Binder for Casting Cores: An Industrial Application to Safety Suspension Parts

Andrea Ferrero and Marcello Badiali
Teksid Aluminum Foundry

Richard Schreck and June-sang Siak
General Motors Research and Development Center

William Whited
GM Powertrain Group

ABSTRACT

A new core binder system (1) was used to produce foundry cores for casting hollow aluminum suspension parts by the low pressure, gravity flow, semi-permanent mold method. These and other prototype aluminum parts made using the system demonstrate that easy core removal from complex castings, core and sand recycling, and an improved environment in the core making facilities will increase productivity, improve product quality and reduce manufacturing costs.

INTRODUCTION

Several commercial processes are currently used at Teksid to produce cores for aluminum casting operations. All of them currently show excellent performance for core production rate, core strength and surface finish, core dimensional accuracy and stability. However, several problems still exist with the two main processes in use at Teksid, the furanic hot-box and the phenolic urethane cold-box process. Both of them use catalyst compounds to improve the speed of the polymerization reactions which are not friendly to the environment or the health of core-shop workers.

In the cold box process, the catalyst is a gaseous aliphatic amine which, despite of the improved gas tightness of the equipment and tools and venting of the working place, can potentially give rise to exposure to workers, and requires scrubbing to purify the exhaust fumes. The hot-box catalyst can release formaldehyde both during core making and casting. Reducing the health and environmental impact of core processes is therefore an important production issue at Teksid.

Despite great improvements in core production machinery, flawed cores in high volume production still represent a net loss of money in a foundry because of the waste of binder and of the energy required to recycle sand. Therefore, introducing an easily recyclable binder that allows reuse of sand and binder from flawed cores was appealing to Teksid.

Due to the relatively low metal temperatures to which the binders are exposed during aluminum casting, oxidation and breakdown of the binder during pouring and cooling of the casting is often very limited. The cores still appear to be very strong after casting and removal is not straightforward, often requiring long cycle time operations and sometimes careful inspection to ensure completely sand free castings.

This problem is exacerbated by the current trend to increase the complexity of core shapes to obtain more complex, higher value-added parts directly during casting, thus reducing subsequent machining operations and costs. Thus, cores must often be removed through narrow and intricate passages in modern automotive castings. Shake-out of core sand may therefore prove to be quite expensive in capital equipment, time and energy required to complete this step.

Mechanical shake-out of sand from massive parts is performed with tools which combine vibration and hammering (generally onto areas of the casting which do not belong to the final part, like risers) and blowing by compressed air jets. This procedure for sand removal may inadvertently convert good castings into scrap because of structural damage to the part, and may therefore increase production costs for complex parts.

A second method for sand shake-out of cores in structurally weaker parts is thermal treatment, with the aim of reducing the core strength, through oxidation of the binder. However this practice can be very expensive due to capital costs for ovens, energy costs and long oven cycle times. The long cycle times are required because of the oxygen poor atmosphere in the core caused by the small openings into the casting and the slow diffusion transport of oxygen within the core to breakdown the binder. Thermal core removal may also produce thermal deformations in the casting which can also increase the scrap rate at this step. Improving the shake-out behavior of cores for aluminum castings was therefore a very important reason for this project.

CASTING ADVANCED SUSPENSION PARTS

Low pressure semi-permanent mold casting was selected to produce cast aluminum suspension parts at Teksid Aluminum Foundry in Carmagnola, Italy. This casting technique is particularly suited to making these parts because of the following features:

- Bottom filling of metal, with low speed and turbulence
- Use of heat treatable alloys is possible
- Fast cooling rate (giving improved metal microstructure and tensile properties)
- Reduction of risers and ingate volume in the part
- Feasibility of producing tubular designs through the use of cores.

Extensive computational work demonstrated that for cast suspension parts a tubular design can help reduce weight (by 5%) and improve performance compared with open-structured castings. Table 1 and Figure 1 show the computations on which the design of a new production rear suspension arm was based. The suspension arm is shown in Figure 2.

Table 1. Reduction in Maximum Stress in Tubular vs. Open-Structured Safety Suspension Arm with Different Computer-Simulated Loads.

Loading Mode	Reduction in Part Maximum Stress (%)
Steering Maneuver (external surface stress)	33
Steering Maneuver (internal surface stress)	25
Braking	66
Vertical Acceleration (bump)	66

Implementation of the low pressure semi-permanent mold technique, combined with exploitation of the Company's core making and casting experience, was therefore introduced to produce cast hollow suspension parts.

However additional core removal problems, besides those outlined above, arise from using currently available core materials for critical safety parts. Specifically, the mechanical shake-out practice is not intrinsically safe for the structural integrity of the casting, and cannot be applied with confidence to safety suspension parts. This is especially true for lightweight tubular designs requiring reduced wall thickness and less overall weight of metal in the casting. Furthermore, when the low pressure semi-permanent mold technique is employed for manufacture, the volume of metal in removable structures such as the risers and ingate is greatly reduced, leaving virtually no surface available for hammering the core sand loose without damaging metal belonging to the final suspension part.

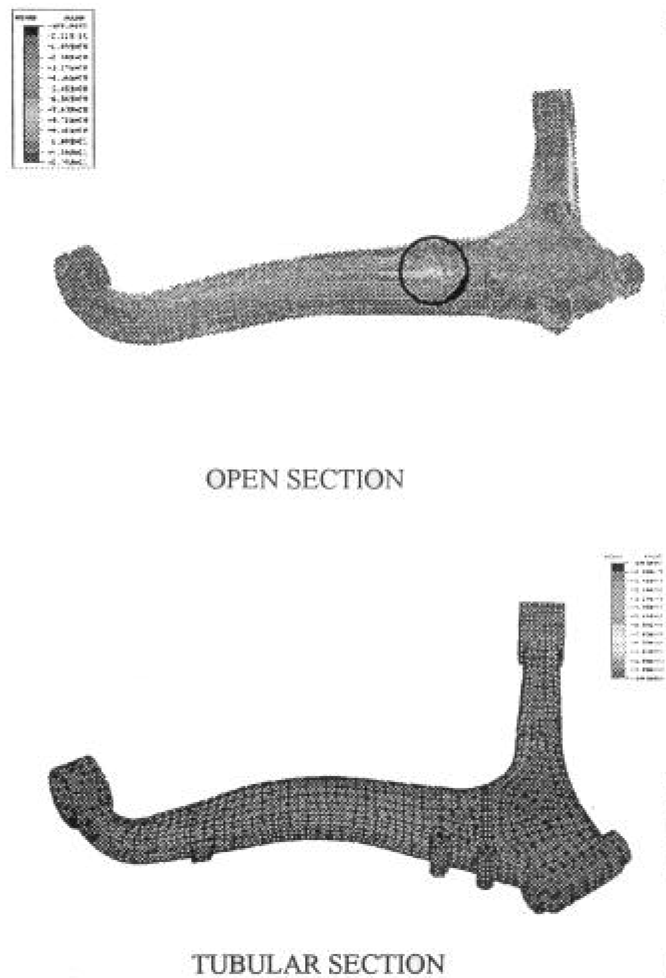

Figure 1. Computer model of loaded suspension arm cast with an open section (upper) shows higher peak stresses, as circled, than the tubular section design (lower).

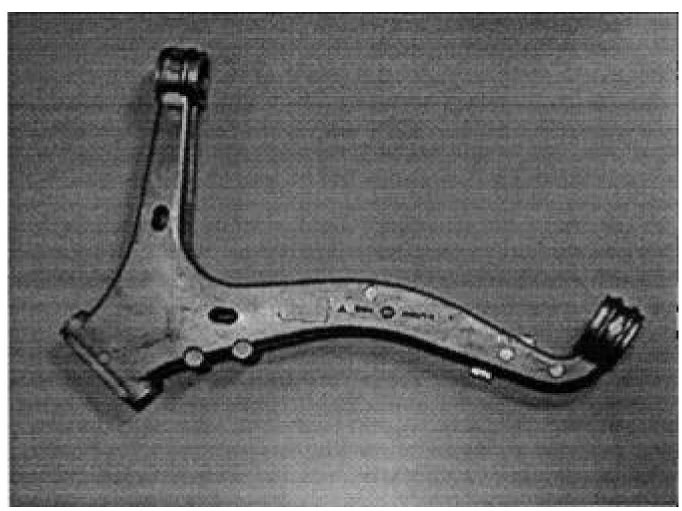

Figure 2. Tubular cast rear suspension arm as removed from semi-permanent mold die.

Thermal treatment was therefore preferable for shake-out purposes on critical suspension parts, unless an innovative core process with improved shake-out performance could be found.

GMBOND™ FOR SUSPENSION PARTS

A new core process called GMBOND™, developed by GM Research & Development Center and GM Powertrain Advanced Development Laboratories, was introduced at Teksid, following a GM-Teksid agreement for the joint industrialization of the process. The first application of the process would be to produce suspension parts cores because of all the above-mentioned difficulties in casting these parts.

This process uses a protein-based biopolymer and is totally water-based. No toxic gases are involved in core production which greatly improved the environment around the core machines. Equipment was added to our current core-producing machinery to correctly apply the binder to the sand and store this mixture until it was ready for use. The core for the new arm shown in Figure 3 was originally designed to be produced by the furanic hot box process.

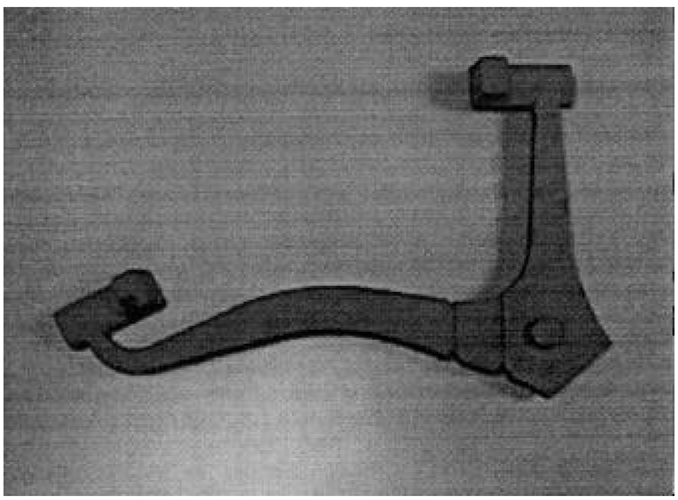

Figure 3. Sand core made by the new binder system for the tubular rear suspension arm.

Consequently, arm cores were produced with the new process using the same hot-box tool as for current cores, but with machine parameters adjusted for the new binder. High quality cores were obtained, having tensile strength and surface hardness comparable to the hot-box ones. The binder content was 45% lower for the new binder and the same sand (lake sand, 55 AFA) was used in both cases to give the results shown in Table 2.

Table 2. Core Strength and Hardness for Conventional vs. New Experimental Core Binder Plus Binder Content and Range of Cycle Times.

	Core Type			
Core Property	**GMBOND**	**GMBOND**	**Cold Box (Phenolic Urethane)**	**Hot Box (Furan)**
Tensile Strength (MPa)	1.92	2.11	3.19	1.79
Surface Hard-ness Arbit. Unit	29.9	59.6	60.9	59.8
Binder Content (wt %)	0.75	1.0	1.6	1.4
Cycle Time (sec)	45-180	45-180	50-75	60-90

Cores produced with the new process were dimensionally checked and showed negligible deviations from the hot-box ones. In fact, they fit easily into the low pressure mold during casting. Casting of the suspension arm was straightforward, without any breakage during core fitting and casting.

Dimensional checks of the suspension arm showed that no deformation of the core occurred during casting and the correct wall thickness could be safely achieved throughout the part. The new binder, in fact, was shown not to be thermoplastic and thus did not deform from the heat of the metal. Also, the internal surface of the arm had an excellent finish.

Shake-out of the cores gave surprising results compared to conventional sand cores:

- Usually the hot-box core can be removed from the arm only through a mechanical shake-out process consisting of two hammering cycles of 20 seconds each, alternated with two vibration cycles of 20 seconds (total time 80 seconds). Due to the risk of damaging this safety critical part, the process for core removal on this part was to be by oxidizing the binder in a high temperature cycle (several hours at 450°C) to weaken the binder for shakeout.
- The new core, after 30 minutes cooling of the casting in ambient air, can be removed in 60 seconds by simply blowing compressed air through the arm. The sand appears to be as loose as after the thermal treatment described above and Loss on Ignition (LOI) measurements indicate that 75% of the binder has decomposed from the heat of the aluminum after this ambient cooling. Using combined vibration and compressed air, a vibration cycle of only 20 seconds, without any hammering, is needed for complete shake-out of the core.
- Alternatively, if a direct quench of the part into water is needed, removal of the core by means of water jet can be performed as well. It has already been noted (1) that the new binder is completely soluble in warm water (> 35 -40°C). We have further shown, by quenching experiments of the arm, that the poured metal (despite of the reduced wall thickness of the arm) can transfer sufficient heat to the core to weaken a layer of binder 6-8 mm thick directly

beneath the metal surface. Water quenching the entire casting immediately after extraction of the part from the mold, even with cold water (10 - 15°C), will weaken the center of the core. After this, fast removal of the wet sand is straightforward, with the aid of a water jet.

Cycle time for core production with the binder using the hot-box tooling was longer than with the hot-box process because this machine was not yet modified to perform the higher speed GMBOND™ cycle (2). At the present time, tests are in progress with specifically designed tooling to verify cycle times expected to be lower than our hot-box cycle. If these tests prove successful, the new core technology will be introduced into production for the new arm cores because of the following considerations:

- The extremely low binder content, required to produce high strength and surface hardness cores, makes it possible to balance lower binder usage against higher binder cost to make the transition to the new binder nearly cost neutral.
- In a new plant, the introduction of the new process will allow saving the capital investments related to:
  a. acceptance, control and storage of the liquid furanic binder and catalyst solution;
  b. venting (and subsequent fumes scrubbing) equipment to guarantee health and safety in the working place around the core machines.
- The excellent shake-out behavior described above, due to the binder's rapid thermal breakdown and water solubility, avoids both hammering for core removal and thermal treatment of castings. This reduces mechanical damage to the casting and eliminates the capital investment and utilities expense of furnace treatment. Eliminating these two methods of shakeout can increase yield (by reducing damaged parts) and reduce floor space and process delays associated with furnace treatment. Further, leaving the option for air jet or quench and water jet removal of cores gives product and process designers additional flexibility to develop new cast products at competitive prices.

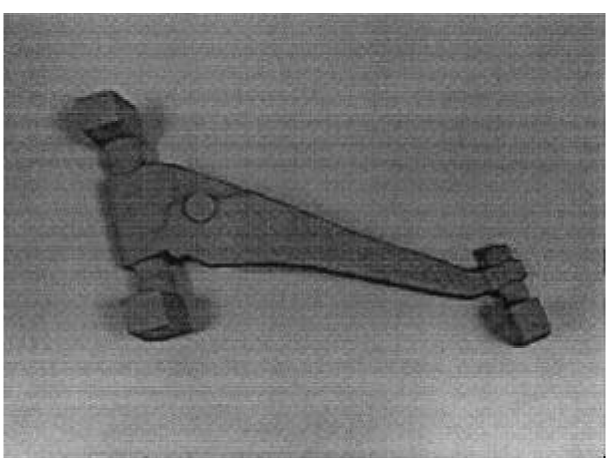

Figure 4. Fiat Punto suspension arm core made from new binder material for aluminum casting.

The new core process was also tested on a shelf suspension part core, the Fiat Punto suspension arm, as shown in Figure 4.

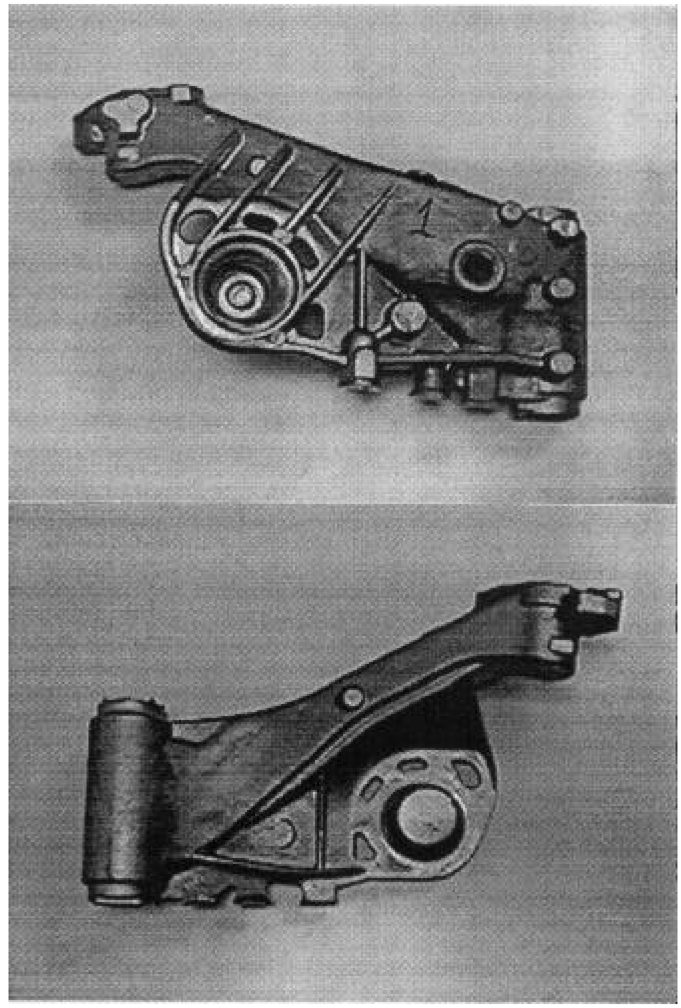

Figure 5. Hollow suspension arm for the Fiat Punto cast with the new core binder and de-cored using either compressed air or a water jet. Both top and bottom views shown.

This arm, shown in Figure 5, was developed a few years earlier to demonstrate the feasibility of producing cast hollow suspension parts through the low pressure semi-permanent mold technique. The cores were originally produced by the cold box process with a prototype tooling and a manually operated core machine. This tooling was converted to the new core process for these experiments.

The new recyclable cores produced on this manual cold box machine had excellent quality and showed the same shake-out behavior as described above. The higher metal mass relative to core mass for this part, when compared with the case of the hollow arm shown earlier, made it even easier to dry shake-out the core due to better oxidation of the binder.

APPLICATION TO ENGINE HEAD AND BLOCK CORES

The new core process was also tested on several current production cores for engine cylinder heads and blocks made by Teksid. The main manufacturing problem issues related to the use of the current hot-box and cold-box core technologies to produce these cores are the following:

- In massive cores (high volume to surface ratio), like the engine shaft or camshaft housing cores which are also used to contain risers and must therefore be very strong, the heat transfer from metal during casting is limited, thus leaving strong, unburned core masses inside the casting after solidification which may be difficult to remove later;
- Modern engine water jacket cores (and therefore water jackets in castings) have increasingly complex shapes and thin walls, which make sand removal from the casting difficult if the binder is not completely burnt from the heat of the cast metal. For both heads and blocks, thermal treatment is often required to ensure complete and safe removal of the sand from the cast product.
- Complex and thin-walled cores like some water jacket cores are often weak and difficult to form, giving rise to high scrap rates in core production. This scrap increases net cost because of the loss of binder and the waste of energy to recycle sand from these scrap cores. If scrap cores could be directly recycled into cores, it would save this cost.

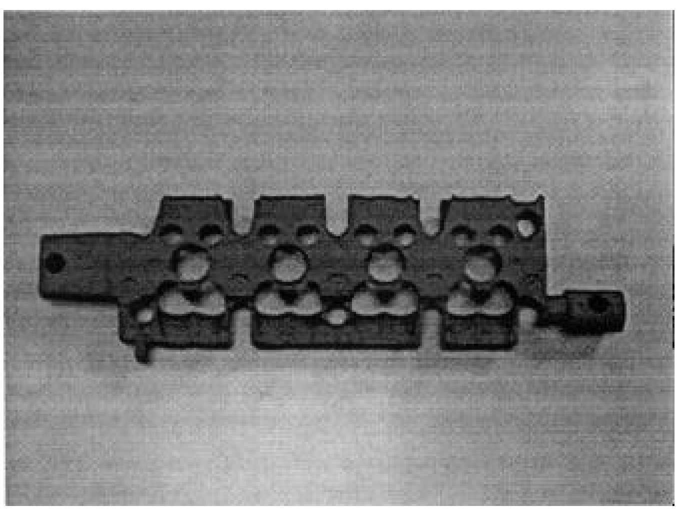

Figure 6. Engine head water jacket core for the “Fire” 16V four cylinder engine.

Cores for two eight valve and one sixteen valve Teksid cylinder head (see Figure 6), and for a V6 (Figure 7) and a V8 engine block were produced with the new binder, using both hot-box and cold-box tools.

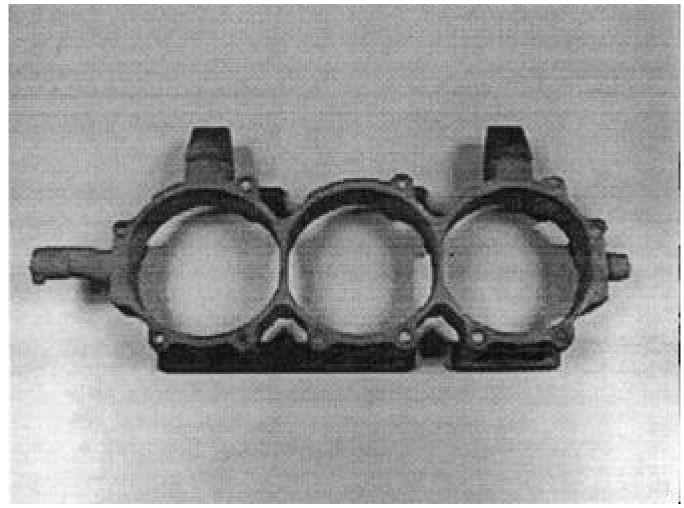

Figure 7. Engine block water jacket core for the Chrysler V6 aluminum engine.

In all cases the strength, surface finish and dimensional accuracy of the new cores allowed casting parts having quality comparable to those obtained with current production cores. The finish grade of internal surfaces was also excellent on these engine castings. Shake-out was again easily performed, without any further heat treatment, in two ways:

- “Dry“ route, by simple air-jet blowing of the thinner cores after cooling down of the casting, and with the aid of mild vibration to help removing the more massive cores that were not completely oxidized by the heat of the cast metal.
- “Wet“ route, by directly quenching the part after extraction from the mold, which caused the largest cores to dissolve into loose sand and to fall out of the casting under gravity, followed by washing sand away from the narrower passages with water jets.

Careful inspection showed that no trace of retained sand could be found, and therefore the potential was demonstrated to ensure, with the new core process, sand-free castings without using thermal treatment and incurring the related capital and cycle time costs.

Moreover, it was demonstrated in these studies that scrap cores could be ground into loose sand and immediately put back into the core machine, together with the waste sand mixture coming from machine cleaning, cycle shut-down etc.. This recycled mixture was used to produce additional cores with only small differences in properties from cores made with unrecycled binder as shown in Table 3.

Table 3. Variation in Core Strength and Hardness with Recycled Sand Content.

	Tensile Strength (MPa)	Surface Hardness (Arbitrary Units)	% of New Sand Strength	% of New Sand Hardness
100% New Sand	2.11	59.6	100	100
20% Recycled Sand	1.98	55.6	94	93
100% Recycled Sand	1.90	48.6	90	82

High quality 8 valve cylinder head cores were produced with 80 / 20 fresh / recycled mixture. This recyclability of scrap cores, together with the low temperature required to completely burn out the binder and regenerate sand from casting shake-out, can lead to important cost savings in the whole core making cycle for aluminum castings, in a manufacturing operation designed to utilize these features of the new process.

CONCLUSIONS

A new, non-toxic and environmentally friendly core making process has been demonstrated on production core making machinery. These cores are easily removed from complex aluminum castings with no thermal after treatment and no potentially damaging hammering of the casting. Consequently, the cores enable the efficient production of safety critical and delicate parts as well as large castings such as engine blocks with fewer manufacturing steps and less energy.

ACKNOWLEDGMENT

The authors would like to acknowledge the encouragement and participation of Prof. Sergio Gallo in the conduct of these studies.

REFERENCES

1. Siak, J-s, W. Whited, R.M. Schreck, M. Datte, and S. Biederman, “Nontoxic, Recyclable, Core Sand Binder for Aluminum Castings,” #96-189, American Foundrymens Society Transactions, pp. 1213-1216, 1996.
2. “Sand Mold and Member Method,“ US Patent No. 5,582,231, December 10, 1996.