FDM of ABS Patterns for Investment Casting

By

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ABSTRACT
This paper will evaluate the suitability of fused deposition modeling (FDM) of acrylonitrile butadiene styrene (ABS) patterns for use in investment casting. The focus is on integration with existing foundry practices. It is a combined industry/university project with the case studies performed at the industrial sites with university produced patterns. Process parameters, ash handling and casting issues are addressed.

2 INTRODUCTION

Fused deposition modeling (FDM) has demonstrated the ability to reduce production time requirements in many applications. Like other forms of rapid prototyping, FDM provides a means of directly creating a tangible 3D object from a CAD/CAM image. On average when compared to machining, FDM has provided a method of verifying designs quickly and often, for a low relative cost. Additional decreases in production time can be obtained, if the FDM Acrylinitrile butadiene styrene (ABS) builds were used as the investment casting patterns. The feasibility of this is determined by addressing casting issues, ash handling, and process parameters, as well as, through thermal analysis and macroscopic examination.

3 GOALS

Our goals are to present casting guidelines for the average Investment Casting Foundry (IC) to use with the ABS patterns. These guidelines involve the use of simple techniques and common materials, and have generally resulted in successful castings.

4 CASTING ISSUES

In order for ABS casting patterns to reduce the investment casting time cycle, ABS must be easily useable with standard practices. Therefore, pattern preparation, gating and venting, investing, burn-out, ash removal, and casting must be considered when determining if ABS is a usable alternative to wax.

4.1 Pattern Preparation

The ABS patterns are robust and easy to work with. They sand well and can be machined. They can be modified with wax to improve surface finish, and combined with waxes to form composite patterns.

4.2 Gating and Venting

For ABS patterns, traditional gating and venting practices require some modifications. These changes can easily be adapted to IC, and must be followed in order to obtain adequate ash removal. It is during the gating and venting design process that the modifications are first introduced.

Ash removal will require low air pressure and water rinsing. Therefore, it is necessary to install additional vents on the pattern. This will improve the air and water feature penetration during the ash removal process. A fair amount of access to the interior of the mold structure is also gained by cutting open the gate end. This too will increase the efficiency and ease of the ash removal. Consequently, it is also important to design the investment tree with the idea that the gate and vent ends will be removed prior to the burn-out process.

Once the investment tree design has been established, standard IC technique is used to attach the gates and venting.

4.3 Investing

A cleaning/etching agent is normally applied to the investment tree prior to shelling. This provides a means of removing any release agents. Once the cleaning/etching agent has dried, standard investment casting procedures are followed in producing the shell. Generally an FDM investment shell is composed of, first, three normal layers, followed by three layers with steel wire reinforcement, with a final seal coat then applied. The number of reinforcing layers can be increased to strengthen the shell when necessary.

After the final seal coat has dried, the tips of the vents are ground to expose the wax. The main sprue is also ground exposing the wax. This modified investing step, must be performed prior to the burn-out cycle.

4.4 Burn-Out

Two methods have demonstrated potential for removing Rapid Prototype (RP) patterns from an investment mold. Though both techniques have succeeded in reducing the pattern and associated material to ash, each has inherent drawbacks.

The autoclave / high temperature burn method is a two step process. First, the mold is placed in an autoclave to remove the majority of the wax from the mold. This step is considered the melt-out cycle, with temperatures ranging between 200 °F to 300 °F (94 °C to 150 °C) (Jacobs 1996). The mold is then transferred, in the second step, to a high temperature oven. At this stage the pattern material is reduced to ash and any residual wax is incinerated. During this stage, the burn-out temperature will range between 1,200 °F to 1400 °F (650 °C to 760 °C) (Jacobs 1996). A disadvantage with this method is that on occasion, the shelling has been reported to crack. This is due to the expansion of the RP material during the melt-out cycle and is addressed by using additional layers and reinforcement..

The temperature for the flash process, starts at 1600°F (871°C) and is elevated to as high as 1900°F (1038°C) for burn-out. This method reduces the RP pattern, as well as all associated tree material, to ash for easy removal. This method too has a drawback. All of the wax in this technique is incinerated, which creates additional smoke during the process.

Both methods have worked successfully with FDM ABS molds. Foundries should determine which method is preferred for their casting process.

4.5 Ash Removal

Removing the ash requires an additional step when casting with a FDM ABS pattern. After the shell has been blown-out with low pressure air and flushed with water, the open gate end and vent openings are resealed with shell repair cement.

4.6 Casting

Casting procedures for FDM ABS mold and traditional investment casting are the same. Standard filling methods and furnace temperatures are applicable.

5 CAST PATTERNS

ABS is the pattern material to be studied. It is the name given to a polymeric structure that represents a family of thermoplastic materials (Smith 1990). ABS is a mixture of three monomers: polyacrylonitrile, polybutadiene, and polystyrene. ABS is not a terpolymer though, it is based on blended copolymers of styrene-acrylonitrile

(70:30) and butadiene-acrylonitrile (65:35) and on graft interpolymers of styrene and acrylonitrile with polybutadiene (Smith 1990) (Sharp 1990). By adding modifiers to the basic ABS mixture, the material properties can be altered. Consequently, the ABS material being evaluated should be the same material that is used during the production of a FDM build.

6 THERMAL ANALYSIS

Thermogravimeteric Analysis Systems (TGA) have proven effective for temperature related polymeric degradation studies. The TGA is designed to measure the change in the sample's mass with respect to the temperature of its environment, even if that environment is altered (Kelen 1983). Several methods can be used to alter the environment: varying the temperature, introducing reactive gases into the sample chamber or a combination of these variables.

After determining the appropriate test parameters, two samples are selected for exposure. The first specimen is the actual sample material; contrarily, the other is inert to the test environment. The inert sample, known as the reference sample, provides a reference point during thermal analysis.

6.1 Graphical Interpretation

Most TGA systems also provide the derivative of the thermogravimeteric curve (DTG) and label the curve, the Differential Thermal Analysis (DTA). The DTA provides information on endothermic or exothermic reactions in the sample material. This is depicted by plotting the change in temperature measurements for the sample against the unaffected reference sample. The endothermic and exothermic points are then useful in determining the temperature at which deterioration of the material properties occurs (Kelen 1983).

7 MACROSCOPIC EXAMINATION

Macroscopic examination is one of the most basic forms of visual examination available. Often used as a prelude to microscopic studies, macroscopic inspection can also be used alone. In this case, inspection of the cast parts will be visually inspected, unless it is deemed necessary to examine a part in greater detail.

8 EXPERIMENTATION

Several builds were produced using the Stratysis 1600. These builds were then used as investment casting patterns and for thermal analysis. The two different types of builds produced were the 3D Systems "Nine-Wall" patterns, seen in figure 1, and the Stratysis "Turbine" pattern, seen in figure 2.

8.1 CASTING

Each sample requires some preparation work prior to casting. Sanding was not required, but a utility knife was used to shave plastic stringers and remove some of the ABS support material. A small screwdriver was also utilized to remove some of the ABS support material from the patterns. The final preparation requirement for each pattern was to fill the small surface openings with paste wax. Approximately 20 minutes was required to prepare each pattern for investing.

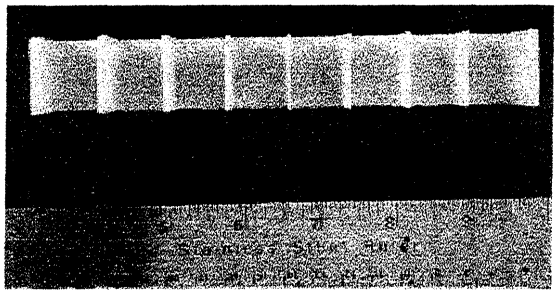

Figure 1 - FDM Nine-Wall ABS pattern

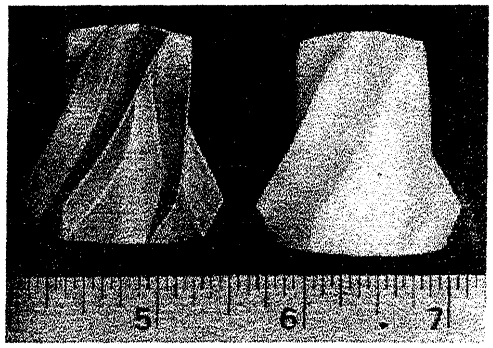

Figure 2 - The as cast turbine pattern on the left and ABS turbine pattern on the right

Some of the patterns were provided to Aurora Engineering for use as casting patterns. A design that would be capable of providing adequate access for ash removal was determined first. The investment tree design and venting arrangement are show in figure 3. The investment tree was composed of a styrofoam core with a wax coating. Addition venting is also evident in figure 3, from the increase in the bleeder wax, that is positioned around the ABS pattern.

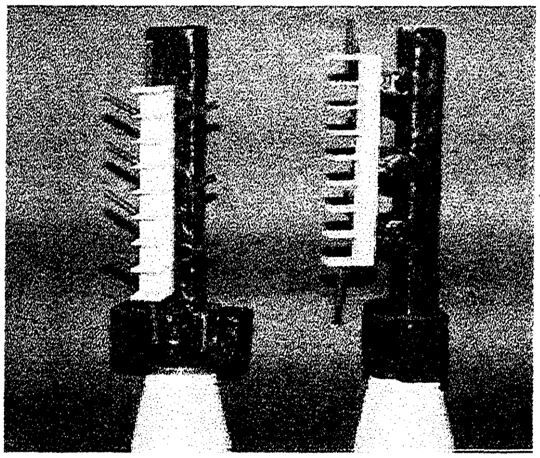

Figure 3 - Nine-Wall pattern ready for investing

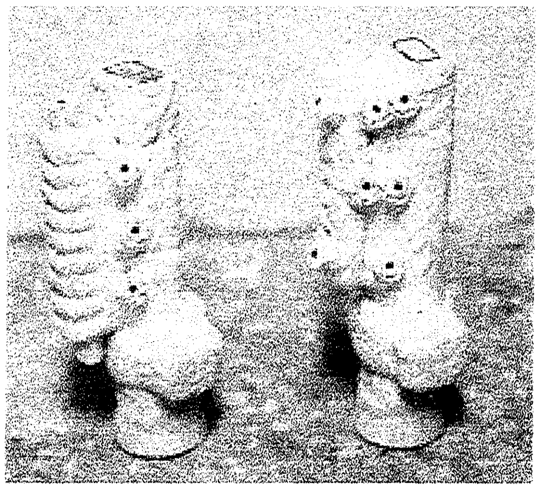

Figure 4 - Invested pattern with gate end and vents opened

The entire investment tree was sprayed with isopropyl alcohol and allowed to dry, in preparation for the investing process. Once the investment tree had dried, it was dipped in a coating solution a total of seven times: three normal coats, three coats with steel wire added, and then one final coat. The final invested pattern is shown in figure 4. The ends of the vents and gates have been removed to aid in subsequent ash removal. Burn-out was performed using the flash process. The molds were placed in a preheated furnace at 1600°F(871°C), immediately raised to 1900°F (1038°C) and left for 90 minutes. After burn-out, the ash (a light white powder) was remove with low-pressure air and water. Mold repair cement was then used to reseal the vent and gate ends.

Standard casting procedures were then followed and aluminum was cast into the molds. The molds at the time of casting were preheated to 1200°F (649°F) and the aluminum was poured at 1285°F (696°C).

The molds were allowed to solidify and the shelling was removed. This produced the as cast structure that is seen in figure 5. After removing the excess material, the gating and venting contact points were ground smooth. The finished products are visible in figure 6, as well as in the Turbine Pattern comparison photograph labeled figure 2.

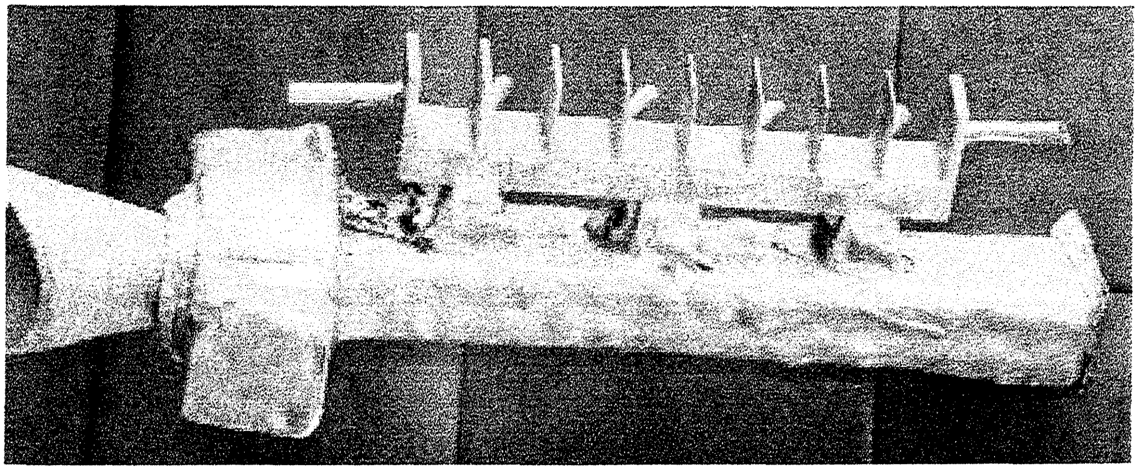

Figure 5 - As cast Nine-Wall prior to removal of excess material

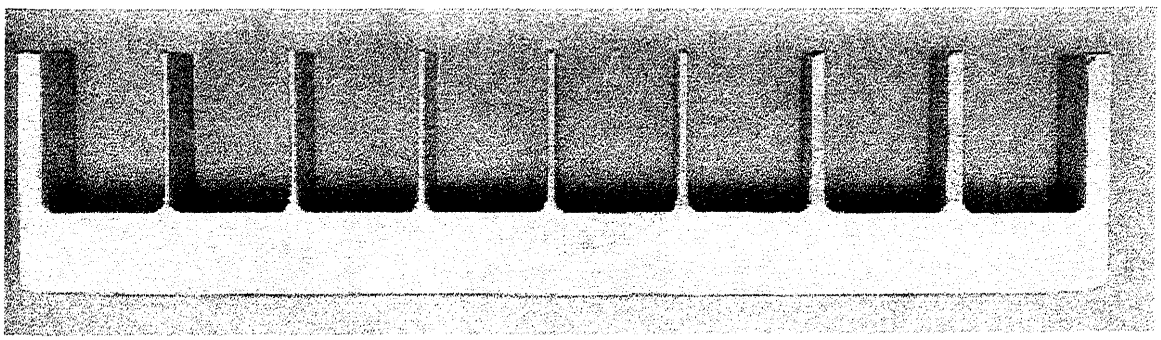

Figure 6 - Final Nine-Wall casting

8.2 Thermal Analysis

ABS Samples for thermal analysis were taken from a Nine-Wall pattern. The TGA test was then programmed to simulate the environment that the ABS would be exposed to, and react in, during the burn-out process. The ABS was subjected to a temperature range that started a 71.6 °F (22.0°C) and was raised to 1112°F (600°C). The gas environment used during the entire test period was air. At the completion of the test, the computer generated graphs showing the weight as a function of temperature, and the derivative of that function. This graph is illustrated in figure 7.

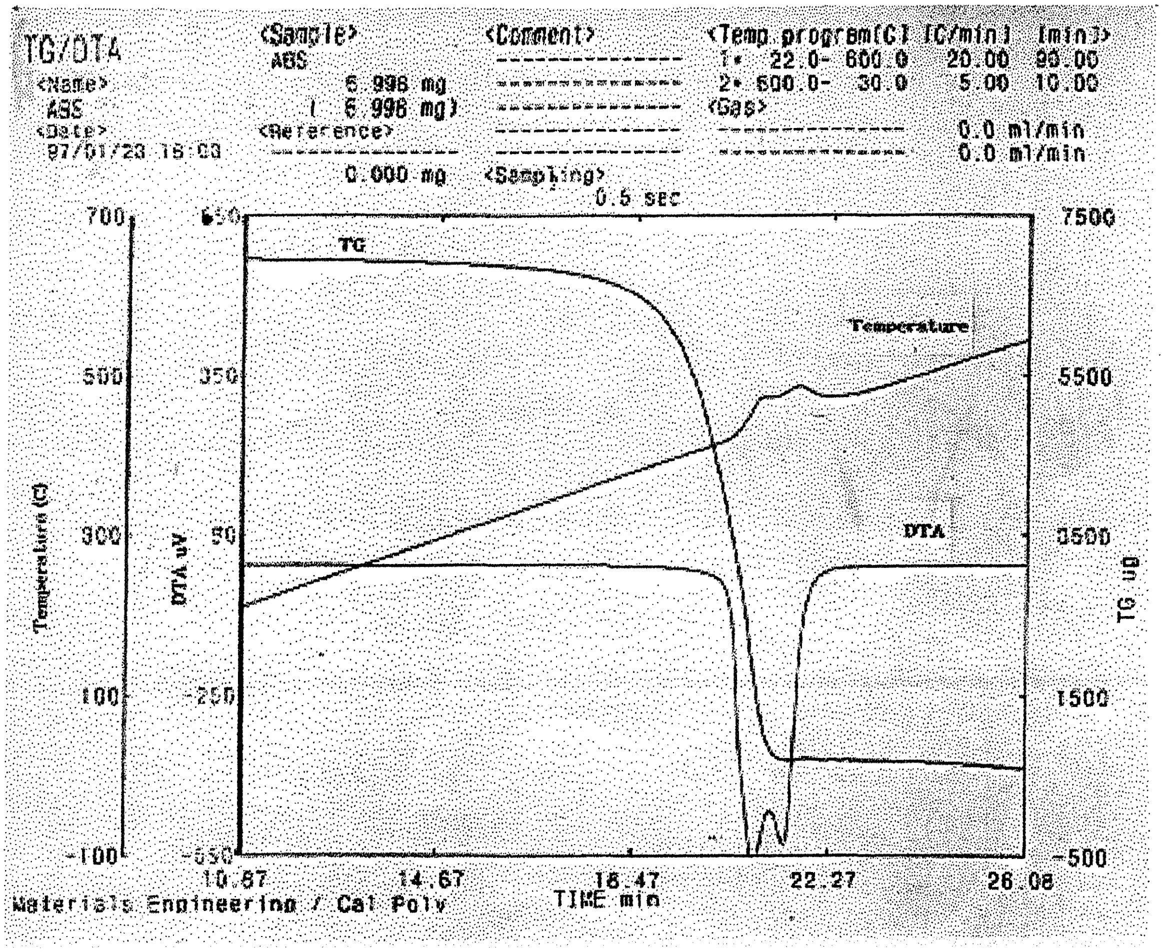

Figure 7 - TGA results showing degradation and exothermic peaks

9 RESULTS AND DISCUSSION

The FDM ABS builds all performed successfully as IC patterns. The ABS patterns, which were built at an academic institution, were transferred to industry and easily assimilated into the IC process.

Upon visual inspection of the final IC cast products, surface appearance was found to be acceptable, and an example of the surface is shown in figure 8. The surfaces in the cast products may be improved further, by increasing the time spent preparing the surfaces of the patterns. Fine, thin wall details, as in the fins on the Nine-Wall pattern and the Turbine pattern, as seen in figures 9 and 2 respectively, were accurately replicated. The only noticeable imperfection was found at the tip of one fin. This was most likely due to the fin cooling too quickly and the metal solidifying before it had completely filled this given area, a cold short.

The TGA confirmed that the ABS material burn-out process is above the required temperature for ABS to degrade. As was evident from figure 7, degradation of the plastic occurs at approximately 797°F (425°C). This is displayed by the exothermic reaction and is estimated from this figure.

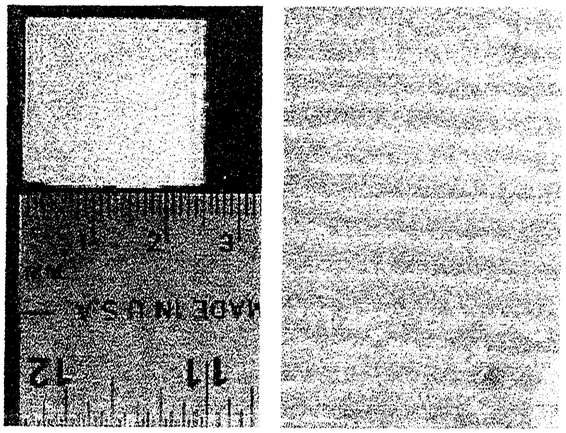

Figure 8 - Magnified view of the same as cast surface. The left picture was photographed with a light macroscope and the picture on the right with a SEM at 22.8X.

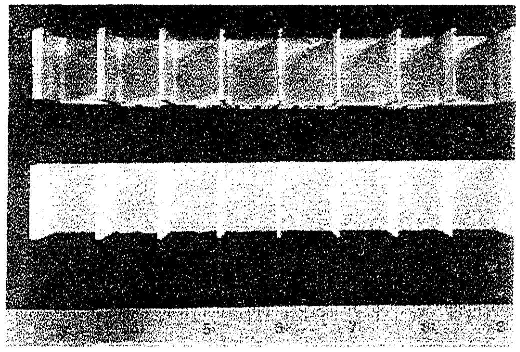

Figure 9 - As cast Nine-Wall on top and the ABS Nine-Wall pattern on the bottom.

10 CONCLUSION

This industrial/university joint project, addressed the IC requirements for FDM of ABS builds to be used as patterns in industry. It was determined that modifications would be necessary, but that these changes are easily adaptable with present IC techniques. Therefore, FDM ABS patterns are suitable for use in investment casting facilities.

11 REFERENCES

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