Manufacturing a Vertically Mounted Sandcast Plaque for The Greenbush Cemetery

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Industrial Sponsors: Fairfield Township, Purdue EPICS

This senior design project through the Purdue EPICS Program is dedicated to remembering Colonel William B. Carroll, a Union solider who died at the Battle of Chickamauga. By manufacturing a plaque that details his contributions to the Civil War and to the City of Lafayette, the EPICS team backed by Purdue's School of Materials Engineering can honor his legacy and his impact on Lafayette's community.

This work is partnered with Fairfield Township through the help of Purdue EPICS.

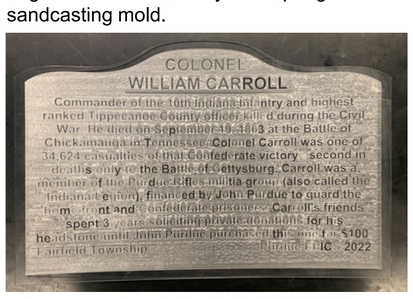
Project Background

Greenbush Cemetery is one of the oldest garden cemeteries in Tippecanoe County and is the final resting place of some of Lafayette's finest citizens as well as U.S senators, abolitionists, and Civil War soldiers, including Colonel William B. Carroll.

There are two community partners involved with this project. Monica Casanova, who is the Fairfield Township Trustee, is the team's main point of contact for details involving approving design decisions. John Collier, who is the Assistant Director of the City of Lafayette's Economic Development Department, acted as a representative for the project during the transition between the previous Fairfield Township Trustee and Monica Casanova's election.

Past Work

Former EPICS teams have gotten the historical content to be displayed on the plaque approved by the Historical Preservation Committee. A past team laser engraved a sheet of acrylic in Spring 2022 to be used as the pattern for the sandcasting mold.



Laser engraved acrylic from Spring 2022 EPICS team.

Example of the 3104-aluminum alloy cutoff pieces donated by Logan Aluminum and used for this project's sandcasting.

Materials

The materials for casting this plaque are cutoff pieces of 3104-aluminum donated by Logan Aluminum and oil impregnated sand.

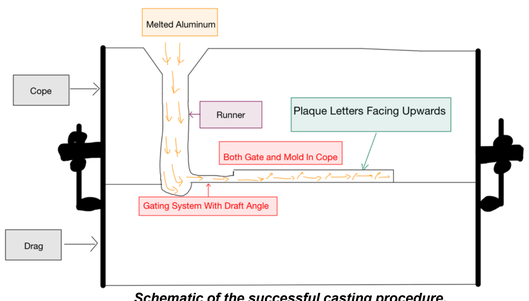
The 3104-aluminum alloy is not meant for sand casting, as it is a wrought alloy. Although sandcasting is normally done with aluminum alloys of the 300 series due to silicon being one of the primary alloying elements and increasing their castability, it is not impossible to produce a plaque of the intended quality using the 3104-aluminum alloy.

Manufacturing Procedure

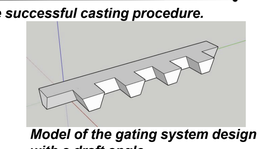
Sand Casting

The most successful sandcast plaque, which was used for the final product was done with the mold in the cope. With the mold in the cope, the melted aluminum would flow upwards to fill the lettering in the mold.

A gating system was also used to assist in maintaining a proper fluid flow pattern. This gating system was designed using wood and implemented a draft angle for easy removal from the sand.



Schematic of the successful casting procedure.

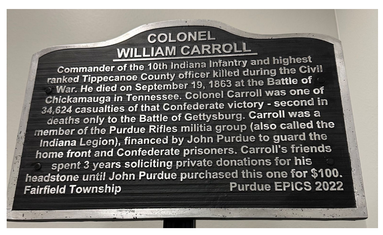


Model of the gating system design with a draft angle
The gating system used for the mold was manufactured out of wood.

Powder Coating

The cast aluminum plaque was powder coated at Sure Tech Powder Coating Inc. with a polyester powder in the color "Blackboard" by the brand Prismatic Powders.

The powder coating process done by the third-party source resulted in excellent quality. The lettering as well as the decorative edge was sanded off to expose the silver of the aluminum resulting in contrasting color between the lettering and the background and making the words easier to read.



Final plaque after powder coating process. The lettering and edges have been sanded off to contrast in color with the background.

Preventing Galvanic Corrosion

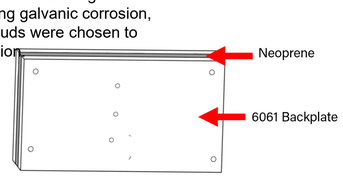
To prevent possible galvanic corrosion caused by the interaction between two dissimilar metals, as cast aluminum and galvanized steel press fit studs, in a moisture rich environment, the plaque was powder coated with the press fit studs installed.

With the press fit studs already installed prior to applying the coating, the coating prevents any moisture to reaching the interface of the two dissimilar metals.

As well as using the powder coating as the primary method of preventing galvanic corrosion, zinc-plated steel press fit studs were chosen to mitigate the onset of corrosion.

Mounting

With the intention to vertically mount the plaque, a 6061-backplate and a neoprene insert were incorporated into the design. The backplate holds three press fit studs that will connect to an1.5 in 80/20 style aluminum post. The plaque connects to the backplate by four press fit studs on each corner. The neoprene insert acts to level the surfaces of the as cast aluminum and the backplate with the additions of the press fit studs and create a more uniform interface between the two pieces.



Schematic of the intended design including a 6061-aluminum backplate, a neoprene insert between the cast plaque and the backplate, and various circles indicating where the fastenings will be placed.

Tracing of the plaque on a 6061-aluminum sheet before cutting with a jigsaw to be used as the backplate for the final product.

Assembly and Installation

After all the tamper proof nuts were installed onto the press fit studs connecting the plaque, neoprene insert, backplate, and post, the nuts were spray painted black per the project partner's request to match the aesthetic of the rest of the product.

The final product will be installed at Greenbush Cemetery by cementing the bottom two feet of the post in the ground while using an anchoring system composed of leftover press fit studs protruding from all four sides of the post in a staggered fashion. Stakes and metal wire will also be used to stabilize the product while the cement hardens. This will be done by the grounds crew at the Greenbush Cemetery.

Anchoring method designed with leftover press fit studs protruding from the bottom of the post from all four sides. Blue tape indicates where the ground will be.

Final product view from the back after assembly.

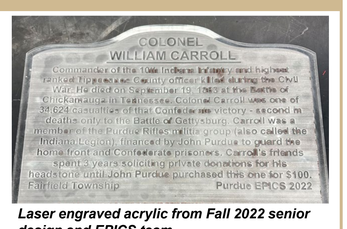
Results

Sandcasting

A total of five castings were completed in the Fall 2022 semester.

First Casting
This casting served as a demonstration for those on the team with no prior casting experience using a small piece unrelated to the project.

Second casting showing illegible letters and areas missing from the plaque.



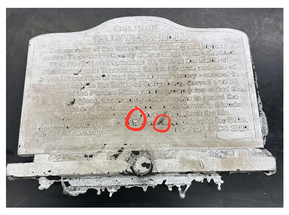
Laser engraved acrylic from Fall 2022 senior design and EPICS team.

Second Casting
The acrylic mold prepared by the Spring 2022 EPICS team was used and too little aluminum was poured into he mold.

Third Casting
A new laser engraved acrylic pattern of better quality that was used as well as a gating system without a draft angle. However, sand broke off into the mold during the casting process and disrupted the casting.

Third casting showing the gating system still attached and the areas in which sand fell into the mold cavity.
This casting was painted blue and then sanded to test if the lettering was more visible with the new pattern.

Fourth Casting
The mold was placed in the drag as opposed to the cope as done in the other iterations. This method resulted in the lettering being of lesser quality. The gating system without a draft angle was used again.



Forth casting showing excess flashing where the gating system was. Red circles indicate areas of lesser quality in the lettering of the plaque.

Final Casting
The fifth and final casting was completed using a redesigned gating system. This time the pattern for the gating system incorporated a draft angle to assist in removal from the sand.

10 lbs. of aluminum was melted and poured in the mold which resulted in this final casting. The plaque itself weighs around 8 lbs. and minimal touchups were necessary because of the excellent surface quality directly after removal from the sand mold.

Successful casting of the plaque directly after being removed from the sand mold.

Heat Testing in Preparation for Heat Cycling Involved in Powder Coating Process

With the goal to powder coat with the press fit studs in the cast plaque in order to prevent galvanic corrosion, it is necessary to be certain that the press fit studs will not loosen during the heat cycling involved in the powder coating process. Sure Tech Powder Coating Inc. sandblasted the as cast plaque with the press fits installed and then cycled the plaque with press fit studs and the backplate in a furnace at 500°F three times for a duration of 15 min each. The purpose of this heat cycling is to burn off organic substances from the surface to ensure a coating of intended quality.

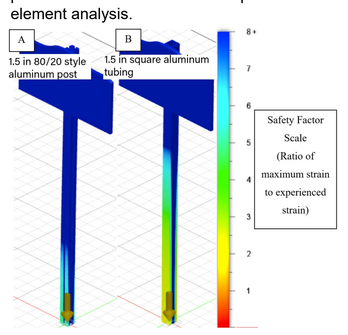
Eight coupons were cut from failed castings, and press fit studs were installed alone in four of the coupons while press fit studs reinforced with Extreme Heat JB Weld paste were installed in the other four. After cycling in a furnace for the same heat of 500°F duration of 15 min that Sure Tech Powder Coating Inc. would, The coupons with the press fit studs with out JB Weld reinforcement loosened and were not fit as securely than before the heat was applied. The coupons with the press fits reinforced with JB Weld stayed secure after the heat testing.

Press fit studs in coupons cut from failed castings. Reinforced with Extreme Heat JB Weld paste meant for temperatures exceeding 1000°F.

Press fit studs in coupons cut from failed castings without the Extreme Heat JB Weld paste.

Finite Element Analysis

An EPICS student working on this project assisted in developing a to-scale model of the fully-assembled product with all materials used inputted in. This model was created in Fusion 360 and used to run a finite element analysis.

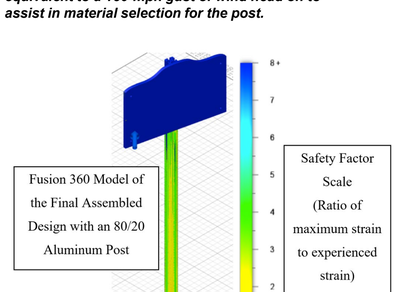


Finite element analysis with applied force equivalent to a 150-mph gust of wind head on to assist in material selection for the post.

One version of the model was designed using a 1.5 in 80/20 style aluminum post and another version was designed using a 1.5 in square aluminum tubing to hold up the plaque.

The first finite element analysis ran was to assist in the material selection of the post, which will hold up the assembled plaque, and to determine if the final assembled product could withstand wind speeds of at least 112 mph which is the highest recorded wind speed in Central Indiana.

The force applied to these two models in the finite element analysis was equivalent to 150 mph head on. Both the 80/20 style post and the square aluminum tubing performed well under this stress test. However, the 80/20 style post had significantly better results and did not exceed a value of 5 on the safety factor scale (ratio of maximum strain to experienced strain).



Finite element analysis with applied force equivalent to 260 lbs. at a 45-degree angle on the bottom left corner of the plaque to simulate blunt force impact due to vandalism.

The second finite element analysis ran was intended to determine effect of blunt impact from a possibly vandal.

The force applied on the finite element analysis was equivalent to 260 lbs., which was determined by researching the average force of a person swinging a baseball bat.

The finite element analysis showed minor damage only at the point of direct impact on the bottom left corner of the plaque. The torsion recorded in the 1.5 in 80/20 style post was within material tolerances.

Discussion

Notes on Iterations During the Sandcasting Process

First Casting

After completing the first casting, the entire team received a better understanding of the casting process. This casting also allowed the team to practice packing sand sufficiently as well as melting and pouring the aluminum into the mold.

Second Casting

The lack of deliverable quality on this casting can be attributed to the protective film not being removed from the acrylic prior to the Spring 2022 EPICS team laser engraving. Another factor leading the the poor quality of this casting was the wrong crucible being chosen to melt the aluminum resulting in not enough aluminum being melted as well as aluminum spilling out of the crucible before making it into the mold.

Third Casting

The patten for the gating system used for this casting did not have a draft angle, which resulted in difficulties in removal from the sand. The difficulties in removal lead to large chunks of sand falling into the mold cavity and leaving large holes in the casting.

Fourth Casting

With the mold cavity being in the drag as opposed to the cope, the melted aluminum was filling downward into the lettering in the mold. This method of casting negatively affected the mold flow pattern and small pieces of sand in the lettering caused the quality of the plaque to be lacking the quality of a deliverable product.

Final Casting

Using the knowledge obtained from the previous castings, this final sandcasting process implemented all of the factors decided to improve the quality of the plaque. A new gating system pattern was designed to assist in easy removal. This gating system likely improved the quality by lessening turbulence in the flow of metal, limiting sand inclusions in the casting, maintaining a uniform thermal gradient, and mitigating erosion resulting in a clean surface finish.

Heat Testing and Powder Coating Process

The coefficients of thermal expansion for the as cast aluminum, steel press fit studs, and the Extreme Heat JB Weld are respectively around 20, 10, and 50 $(10)^{-6}$ m/m°C.

When the coupons of as cast aluminum with only the press fit studs installed were exposed to the 500°F furnace heat, it is possible that the aluminum, with a higher coefficient of thermal expansion than steel, expanded and the contracted around the press fit studs resulting in the press fit studs loosening from the as cast aluminum.

The coupons of cast aluminum with the press fit studs reinforced with the Extreme Heat JB Weld, were exposed to the 500°F furnace heat, it is possibly that due to the high coefficient of thermal expansion of the JB Weld, the press fit studs were able to remain secure after each material finished expanding and contracting.

During the powder coating process, the press fit studs remained in the as cast aluminum plaque as intended. The powder coating was also able to fully encapsulate the press fit studs in the aluminum plaque thus not allowing moisture in and mitigating galvanic corrosion.

Finite Element Analysis

Based on the information received from the finite element analysis, the 1.5 in 80/20 aluminum post is well suited for use as the post holding up the vertically mounted plaque. The maximum recorded wind speed in Central Indiana is 112 mph, and this model of the final product withstood a force equivalent to 150 mph winds head on. With the expectation of the wind speeds in Greenbush Cemetery not exceeding 112 mph, this final product design should be sufficient to withstand windy weather conditions.

With an understanding that vandalism is a concern of Fairfield Township regarding the Greenbush Cemetery, it is necessary that the team had information regarding blunt force impact on the plaque. Based on the information gathered from the finite element analysis, the plaque should be able to withstand extreme minimal vandal force with minimal damage.

Although this final product performed well using modeling software to simulate responses to certain conditions such as high winds and vandal blunt impact forces, the product may behave differently in its true state. This is due to the inability of modeling the exact specifications of the as cast aluminum plaque, and other factors environmental factors that may cause the product to behave differently over time. Despite the product possibly behaving differently than the model did in the simulation, the team is confident that the final product will last at least 30 years, the expected amount of time detailed by the community partner, because of the materials chosen which are meant to withstand environmental conditions.

Conclusion

The EPICS Program has plans to work with other community partners to design and manufacture similar plaques, and this senior design and EPICS Team obtained necessary information for future teams to apply and obtain similar quality results from the casting process.

Recommendations for Future Senior Design Students Working on Manufacturing Sandcast Plaques Through EPICS or Future EPICS Team Members

It is unknown how much more difficult the 3104-aluminum alloy was to use during the sandcasting process as opposed to a 300 series aluminum alloy meant for sandcasting. Advice to future students working on this team would be to compare the two alloy types of aluminum during sandcasting process to obtain more insight on the properties and behavior of 3104-aluminum being used to sandcast.