**GRAPHENITE™ WX COMPOSITE**
**Investment Casting Processing Guide**

## Introduction

The manufacturing of metal objects in complex geometries is historically an expensive and complicated undertaking. The use of 3DP Printers to build investment casting patterns is an effective way to make that process more affordable, faster paced and less restrictive. Investment casting patterns made on 3DP machines have several process advantages that should be considered when evaluating or planning a casting project.

- Ability to make parts in a wide range of high performance metals
- Free form geometries are possible at no penalty and with no tooling
- Standard shell materials can be used, integrating into standard foundry practice
- 3DP machines have very fast build times and use non-toxic materials
- 3DP pattern cost compares favorably to other RP patterns or tooling costs

This guide describes the steps required to transform 3D CAD data into cast metal parts. As in any manufacturing process, the final quality of a part can improve with custom process modification. This guide can serve as a starting point for any casting being produced with **Graphenite WX** powder based investment casting patterns, but geometry or material specific process adjustments might yield higher quality.

## Part Design

When designing a part for 3DP pattern based investment casting (IC), standard IC design practice should be followed. The Investment Casting Institute (Montvale, NJ, USA) and the American Foundry Society (Schaumburg, IL, USA) have several publications 1 and regular training sessions regarding sound casting design. A discussion of that practice is beyond the scope of this guide. In addition to following best practice for casting design, the following points should be kept in mind when designing your **Graphenite WX** pattern.

- Minimum part wall thickness of 2.35mm (0.09”) is recommended but is geometry specific, thinner sections of 1.5mm (0.06”) have been achieved
- Surface offset or scaling should be used to accommodate for wax build up of approximately 168μm (0.007”) per face. This can be done in 3D CAD Software.
- Shrinkage accommodation should be added to the part’s CAD data or in ZPrint, the pouring foundry should supply shrinkage figures, bear in mind that casting shrinkage is in reality not only a linear scalar, but is geometry dependant. If no I nformation is available a general starting point of +2% can be used.
- Thick sections >17mm (0.67”) can be created with shelled, ribbed and sealed patterns, to reduce build time, pattern material consumption and distortion due to high wax loading, burn out time will however, be similar to a solid pattern.
- Gates and vent locating bosses, with a recommended area ratio of 1.0:0.15, can be added to the pattern in CAD. However the use of standard wax gate and vent length sections will aid in pattern burn out.
- Provisions for handling the pattern during wax dipping should be made. Printing handles or tabs by which to hold the part during dipping is recommended.
- The low green strength of **Graphenite WX** makes means that cantilevered sections should be accounted for if sub millimeter tolerances are desired, either by adding

additional cast in supports or printed fixtures drawn in CAD or ZPrint
- Circular sections should be oriented on the build plate plane for best tolerances
- *.stl file tessellation will affect dimensional fidelity, use ample triangulation to avoid "bad triangles"

Pattern Building and Cleaning Once the *.stl data has been generated the pattern can be built in **Graphenite WX** powder with GRAPHENITE™ CL binder. Default printer settings can be used when building patterns, however this is an area when part specific quality can be improved after initial trials. As mentioned in the list above, the use of fixtures is encouraged if tight tolerances for unsupported structures are desired. For patterns with wall thicknesses at or above 2mm (0.09") bleed compensation should be used. Use of a build plate for easy handling is recommended. After the build has been completed, the parts should be allowed to rest in the powder bed for one to two hours, but no more. Bulk de-powdering should then be done to the extent to which the parts can be removed from the machine and a majority of the part's surface area is exposed. For the best results **Graphenite WX** patterns should not be handled with ungloved hands at any time. Skin oils can affect wax infiltration and burnout. Upon removal from the machine the parts should be allowed to dry for another period of 1-2 hours prior to compressed air cleaning. This drying can be accelerated by the use of an oven or furnace at a temperature below 65°C (150°F). Take care not to damage the green part when cleaning, and to remove all un-solidified powder from its surfaces.

**Pattern Waxing**

The cellulose based **Graphenite WX** pattern now must be sealed before a shell mold can be built up around it. In addition to sealing the pattern, the wax will serve to aid in pattern evacuation and surface smoothing. A two dip approach has been found to yield the best overall pattern in terms of surface smoothness and dimensional accuracy. The ideal wax to use will have a melt temp below 70°C (160°F), low molten viscosity and low residual ash content. The medium grade tissue embedding wax, sold by ZCorp, is suitable as are certain foundry pattern waxes. Higher melt temp waxes should be avoided however, as during the dip process they can more easily distort thin walls due to the temperature's affect on pattern bonds during dip and a longer freezing time. Either a ZCorp supplied waxing machine or user sourced waxing equipment can be used. Wax temperature is critical, as is dwell time control, pattern removal rate and cooling rate. The following dip parameters can be used as a starting point for making **Graphenite WX** patterns.

- Heat a sufficient volume of wax to 70-77°C (160°F-170°F)
- Take care not to handle the pattern with un-gloved hands at any point
- Orient the pattern over the wax such that any trapped air in the part has a route to flow out of the pattern and no surfaces will allow pooling
- Slowly dip the patterns into the wax at a rate of about 10mm per second (0.4"/s) until the pattern is fully immersed, if the pattern is immersed too quickly trapped air might rupture or distort the pattern walls
- Allow the pattern to dwell in the wax for approximately 10 seconds with light agitation. The most important factor in dwell time is that it allows for the cessation of all significant air evacuation from the pattern
- Target wax shell infiltration depth is 5mm (0.20")
- Begin removing the pattern from the wax at an even rate of about 10mm/s (0.4"/s) be cognizant of any geometry specific pooling or drips.
- Allow the pattern to cool to ambient temperature
- The second dip can be done at a higher entrance rate of 50mm/s (2.0"/s) with no dwell time upon full immersion
- Pattern removal on the second dip should be done at a slow, even rate of about

10mm/s, such that the wax may freeze upon leaving the molten volume. This stage is critical to achieving a good surface finish. Fans can be used to help at this stage.

- Cool the patterns quickly to prevent run off or slumping of the surface coat Noble 3D
- Careful mechanical and thermal surfacing can be done to correct any defects or improve the smoothness of the wax. Hot air guns and wax trimming tools can be purchased from art supply stores for this purpose.

**Pattern Shelling**

Upon cooling of the patterns they may be shelled with standard foundry practice and materials (6- 8 layer colloidal silica, zircon sand, and fused silica shell). Lower shelling time chemistries are also available at some foundries. No acid based cleaning agents should be used on these patterns, as if they have been handled properly there should be no surface oils to cause shell bond failure. If the refractory coating is not adhering then a light coating of hair spray ("Aquanet" hair spray works, PVA is the probable, active ingredient) can be used prior to shelling. The shell material provider, if not the pouring foundry, should be able to supply specific shell build up procedures.

**Pattern Burnout, Cleaning and Pour**

**Graphenite WX** must now be evacuated from the shell; to do this a furnace cycle is used. One should note that burning a **Graphenite WX** pattern from a shell requires a different process than melting out a wax pattern. After shelling, the shell molds should be arranged in the furnace* in a flow-friendly orientation (not too tight, gates and vents exposed). The manufacturer of the shell material can inform you as to the maximum temperature at which the shells can be inserted into the furnace in order to avoid thermal shock failure. Whether the shells are inserted into a cool or hot furnace, the target burn out temperature is 870°C (1600°f). The user should be cognizant of the natural temperature gradients that occur in all furnaces and avoid shell placement that does not achieve the target temp. Higher temperatures of 926°C (1700°F) have been used, but on standard thickness patterns the higher temperatures have not shown a drastic reduction in burn out time. In the first burn out cycle for a new pattern a time at target temp of four (4) hours can be used. Patterns up to 20mm (0.78") in section thickness have been evacuated in less than four (4) hours, but optimal in-furnace time is dependent on a number of variables. As the **Graphenite WX** burn out process can not rely on the melting of the pattern material, substantial in-furnace and in-mold gas flow will aid in pattern evacuation, as will an oxygen rich environment (which is typically part of furnace control). After a sufficient time at target temperature has passed the hot shell molds should be removed from the furnace with care. It is recommended that compressed air be used to blow out any sedentary, residual pattern material but extreme care should be taken when introducing increased oxygen to a hot mold. The molds can then be moved into the pouring position per standard foundry practice. If the mold requires bore scope inspection or the user wants to be absolutely certain that no residual ash is in the mold; they can be allowed to cool and then washed with a minimal amount of high pressure water. A typical 19mm (.75") shell can cool from target temp to ambient in approximately three to four hours. Water can then be used to clear the mold cavity. However, in most instances this should be unnecessary if good burn out practice has been followed. If a water wash is used, the patterns must be thoroughly dried (typically over 12 hours) and then reheated prior to pouring.

Molds made from **Graphenite WX** patterns can then be poured in any metal that is compatible with the shell material and casting process used. After pouring the castings can be de-molded per standard practice. One should consider that the use of 3DP technology for shell molds can create free-form casting geometry that is difficult to de-mold. The resulting casting can be cleaned, blasted or surfaced as any other investment casting can be.

∗ Noble 3D recommends the use of a vented oxidative furnace with additional forced turbulent airflow

**Expected Casting Dimensional and Roughness Performance**

It should be noted that the dimensional fidelity characteristics of a **Graphenite WX** pattern will be different than from a wax pattern. While the distortions associated with an injection molded wax pattern (typically due to freeze rates and specific geometries) are avoided, the pattern produced on a 3DP machine has its own typical deviation. Unlike a molded wax pattern, 3DP machines tend to display a near uniform deviation in the XY plane (build plate) and slightly worse tolerance in the Z axis∗, regardless of dimension size. The wax dipping process can, if done incorrectly, induce slumping of thin walls. This should be accounted for in the design of the pattern and fixtures. Castings made with **Graphenite WX** patterns should exhibit the following sample dimensional fidelity and roughness characteristics.

- 0.58mm (0.023”) on linear dimension up to 220mm (8.67”)
- 0.38mm (0.015”) on radial dimensions up to 22mm (0.87”)
- 3.5µm (0.0014”) surface roughness average (Ra)

These values are comparable with base level investment casting industry standards for deviation1. So long as the patterns were properly evacuated the resulting metal should be of a purity level comparable to wax pattern based castings produced under the same conditions. More detailed information2 on the experiments that were used to establish the parameters recommended in this guide can be found in the reference section. Using this guide as a starting point, free-form investment castings of good quality, in a wide range of materials can be affordably manufactured in a matter of days. The use of your 3D Printer for investment casting patterns is yet another way Noble 3D technology can be leveraged to advance your additive manufacturing capability. Sample castings made in 316L SST from **Graphenite WX** patterns.

**References**

1. Bidwell H. T., “Investment Casting Handbook”, Investment Casting Institute, 1997, ISBN-75206-1602
2. Lyons B., “3DP-Based Investment Casting; Summary of an Evaluation for Additive Manufacturing”, Proceedings of the 2007 TCT Conference, Coventry, UK