Reverse Engineering and Rapid Prototyping
A Case Study for the Foundry.

Glenn Powell – Industry Specialist Rapid Prototyping
Concentric Asia Pacific – Advanced Manufacturing Facility

Abstract

This presentation applies some of the newer technologies available today to a foundry application. The two technologies to be discussed are non-contact laser scanning for reverse engineering and dimensional inspection and Selective Laser Sintering Rapid Prototyping process for sand casting patterns and direct sintering of sand cores. The best way to explain these technologies and how they can be applied is to describe a recent case study where three castings of a Ricardo E6, single cylinder, variable compression research engine cylinder head were produced.

Reverse Engineering - The geometry of the cylinder head was captured using a combination of a Faro portable coordinate measuring machine and a Model Maker non-contact laser scanning head. The Probe of the Faro arm was used to capture the geometric features such as machined faces, bolt holes and mounting locations while the laser scanning system was used to capture the freeform shapes such as inlet and exhaust ports, recessed areas and fillets. This data was taken into CATIA V5 modelling software and used as a guide to generate 3D CAD data for both Casting and Machining processes.

Rapid Prototyping - Sand Casting was chosen as the casting process therefore patterns were required for creating sand moulds, and sand cores required for the water jacket, inlet and exhaust ports. Selective Laser Sintering (SLS) CAPForm glass filled nylon was chosen for the pattern as it is tough, can be easily finished to high quality surface finish and a lead time of only 3 working days. Due to the complexity of the corebox required to make the sand cores for the water jacket the decision was made to build the sand cores also using the SLS process but by directly sintering sand coated with a heat set resin. The SLS process builds up models layer by layer using a CO2 laser to fuse materials without the need for coreboxes or tooling, in this instance the heat of the laser was used to partially set the resin applied to the sand to build up the core in 0.2mm layers. When the partially cured or green core has finished building and is removed from the machine it is fired in an oven to fully cure the resin.

Laser Scanning for Inspection - To ensure the sand core had the accuracy required for this casting and that the core had not “sagged” during the oven curing stage we used the non-contact laser scanning system to scan the core capturing the exact shape of the core into the computer. This data was overlayed over the original Cad data by aligning similar features and a distance analysis performed which highlights any discrepancies in the shape of the part.

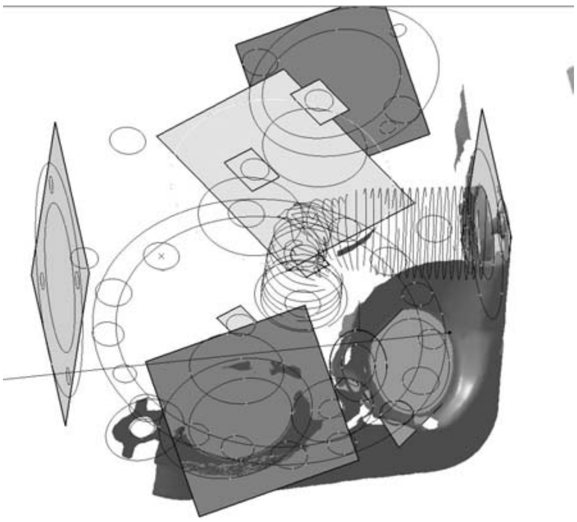
Moulding and Casting - From this point on the process of casting the cylinder heads was along conventional lines, using the SLS pattern to create sand moulds, assembling the SLS sand cores into the moulds and casting the cylinder heads in a mildly alloyed Grey Cast Iron. The final machining was to be performed by the customer.

Introduction

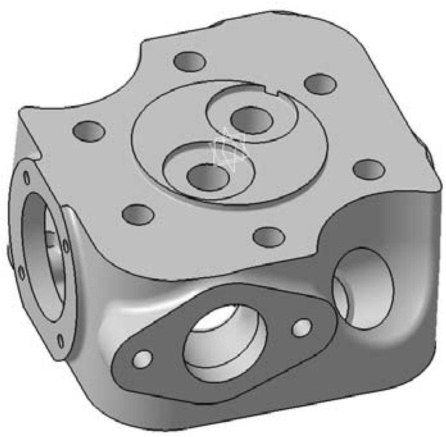
This presentation is about some of the newer technologies available today and how they can be applied to a foundry application. The two technologies in particular are non-contact laser scanning for reverse engineering or inspection and Rapid Prototyping for creating sand casting patterns and direct sintering of sand cores. The best way to explain these technologies and how they can be applied is to describe a recent case study where three castings of the cylinder head of a Ricardo E6, Single Cylinder, Variable Compression engine were produced using a combination of these processes. This engine is a specialist research engine designed by one of the pioneers of the internal combustion engine, Henry Ricardo. Design of the engine dates from the 1920's with this particular engine dating from around the 1950's but it still gets a very hard life as a test engine in a laboratory at the University of NSW. Due to the age of the unit no detailed drawings could be found let lone 3D Cad data so our first task was to generate a 3D CAD model from the existing cylinder head.

Reverse Engineering

The aim was to produce a data set that could be used for all of the required downstream processes such as creating patterns whether by machining or Rapid Prototyping, creating coreboxes or as we used in the end direct sintering of a resin coated sand as well as providing a model for final machining of the casting.



Combined Probe and scan data



Final 3D CAD model

Concentric's in-house laser scanning capability was utilised to capture an exact digital replica of the cylinder head. The system used was a combination of a Model Maker non-contact laser scanning head coupled to a Gold series Faro arm.
The Faro arm is a highly accurate, portable coordinate measuring machine that has 7 axis of rotation giving the unit the ability to probe points with an accuracy of 0.05mm anywhere within a 2.4m diameter sphere. The Model Maker laser scanning head is mounted to the arm along side the probe giving the system the added ability to capture mass data of free form shapes within a tolerance of 0.1mm.
In operation the laser scanning head, using the Faro arm for all positional and movement information, projects a 70mm wide laser stripe that is swept over the part to be scanned creating a moving profile. This profile is captured by a digital camera mounted in the scanning head at a rate of 30 stripes per second. The resultant data set is a dense three dimensional point cloud that accurately represents the shape of the physical part and can be combined with probed data from the Faro arm of features such as datums, planes, circles and points.

The majority of the geometry of this particular cylinder head was made up of fairly simple features and therefore the probe was used to capture this information. The laser scanning system was used to capture all of the freeform shapes that made up the remainder of the cylinder head such as inlet and exhaust ports, recessed areas around the spark plugs and some fillets. This data set was taken into CATIA V5 modelling software and used as a guide to generate 3D CAD models for both Casting and Machining processes.

Rapid Prototyping

SLS Nylon Patterns

Sand casting was chosen as the casting process which therefore required a pattern to create the sand moulds.

Concentric has the largest capacity of Selective Laser Sintering rapid Prototyping machines in Australia with 3 machines locally in SA and 1 in Qld, and with a material ideal for creating sand casting patterns the SLS process was an obvious choice.

The CAD data was set up with the necessary core prints and shrinkage allowance and translated into STL format, a triangulated facet format required for Rapid Prototyping.

Selective Laser Sintering (or SLS as it is known) builds up models layer by layer in functional materials to created tough and durable models. In this case CAPForm, a glass filed nylon 12 material was chosen as the very fine particle size provides a high quality surface finish and excellent feature definition, it is tough and hard wearing, and with a lead time of only 3 working days meant timing was not going to be an issue.

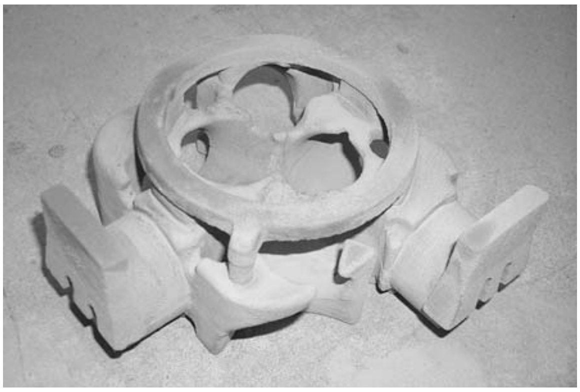
CAPForm SLS glass filed nylon Pattern

The SLS process works by heating a bed of powdered material to a few degrees below it’s melting point in an inert atmosphere and a computer controlled 50W CO2 laser raster scans across the bed, switching on and off at the right time, to melt the cross sectional area of a slice through the 3D CAD model. A piston then drops the bed down by 0.1mm, a roller adds another layer of powder and the laser melts the next slice through the CAD model. This process continues building up layer by layer until the model is completed.

Once the part is cool and removed from the machine it is then hand finished to the desired finish level, in this case very smooth, and is ready to use.

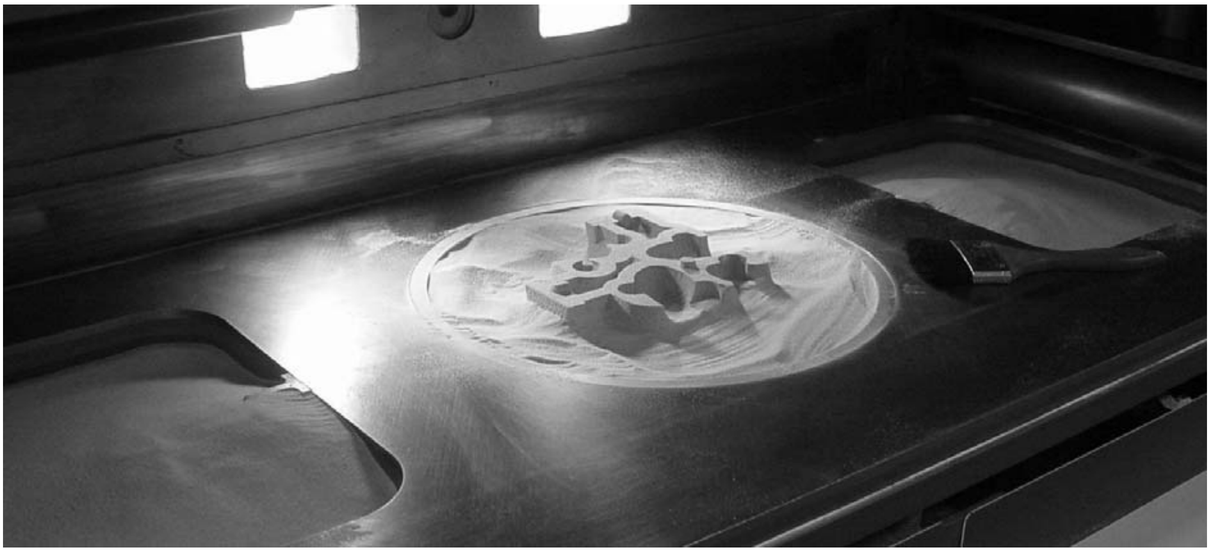
SLS Sand Cores

SLS water jacket Sand Core



Due to the complexity of the corebox required to make the sand cores for the water jacket, and the requirement for only three castings, the decision was made to build the sand cores also using the SLS process directly in sand coated with a heat set resin. This is a process that was first tried when the Advanced Manufacturing Facility (AMF) was part of the SA Centre for Manufacturing (SACFM). At that early stage a few trails were undertaken with Castech, CSIRO and Castalloy but the process did not really get off the ground due to difficulties with sourcing the sand from America and the high resin content making casting and breakout difficult. At Concentric we are undertaking to reintroduce the process again only with help from Darren Trigg at Resin Sands who is working on locally producing a clean and fine grade of sand and varying the resin content to tune the process to be more user friendly for all.

The way that the process works is basically the same as with the nylon powders. We start with a 3D CAD model of the sand core in STL format which is built up in layers only instead of the laser melting the material as it does with the nylons it partially cures the binder applied to the sand. The layers are usually around 0.2mm thick, the sand down around the 100 micron average particle size and the resin content around 4%. Once sintering of the part is complete it is removed from the supporting, unsintered sand by brushing the lose sand away and lightly blowing with compressed air. The parts is in a green state and still needs further curing which is done in an oven at around 150ºC. To prevent the core sagging or changing shape during the oven cycle the sintered sand core is placed in a vat and fully surrounded with a fine glass bead for support. The vat is place in the oven for around 4 to 5 hours to allow the sand cores to fully cure.



Sand Core in SLS machine

With this particular water jacket sand core one of the main worries was gas emission. The core has a large surface area, is almost fully enclosed by the casting and with the SLS sand material requiring around 4% resin content there had to be a way for the gas to vent. One of the advantages of the SLS process is that as parts are built up layer by layer, and as there is no tool that you are constrained to removing the part from, any geometry can be built including undercuts, trapped voids etc. In this case we hollowed the STL file out to a 6mm wall thickness which gave the core enough strength in the green state to handle and remove from the SLS machine but reduced the sand mass and provided an escape route for the gas out through the core prints.

Laser Scanning for Inspection

The complexity of the sand core for the water jacket not only made it difficult to manufacture but also to measure. As this SLS Sand process was still being developed the accuracy of the part was of particular interest not only of the overall dimensions of the outside but also in the internal shape or form of the core which determined the wall thickness in some critical areas of the casting. Another point of interest was to see if the oven curing stage had any effect on the size and shape of the core. Once again we used the laser scanning system to accurately capture the actual shape of the sand core. This point cloud was taken into CATIA V5 and aligned to the original CAD data. This alignment was done by selecting a few specific features on the point cloud and aligning them to their corresponding features on the CAD model. Once aligned a distance analysis was performed where each individual point in the cloud is assigned a colour depending on its distance away from the surface it represents. The result is colour map image of the part that shows trends and errors in the shape of the part.
This method of inspection is ideal for determining the accuracy of parts made of soft or loose materials, as it is non-contact, and also parts with a lot of freeform geometry as it does not rely on specific points referenced to hard positions but instead many thousands of points covering all areas of the part. It is also a quick way of communicating the true state of the part with people who are not adept at reading dimensional reports or spread sheets as the colours of the points can be set to highlight areas that are in or out of tolerance.

Moulding and Casting

The proof of applying these new processes into the foundry comes from the results gained in the moulding and casting process.
Laser scanning capabilities have improved markedly with the advent of small, high resolution digital cameras and the data quality and speed of capture is now at a stage where reverse engineering is a realistic and viable option to copy existing components.
Creating sand casting patterns using the Selective Laser Sintering process is well established but with the improvements in available materials the results are getting better all the time. The mould created with this SLS CAPForm sand casting pattern proved quick and effective. The pattern is accurate to within 0.25mm, has a smooth high quality surface finish, is tough enough for making many sand moulds, available in less than 3 days and is cost effective. What more could you ask for?
The sand cores created directly using the SLS process also proved quick and effective. In this instance the sand cores were successful in assembling well into the sand moulds and providing the three quality cylinder head castings required.
The real positives that can be gained form the process of using the SLS Rapid Prototyping process for patterns and direct sintering of sand cores are Speed and Cost. Turn around times of 3 days for patterns and 3 sets of sand cores with no time or cost required for Cad work to model difficult core boxes proved very valuable.
Two main issues did arise relating to the sand cores which are currently being addressed were gas emission and surface finish. The gas issue was mostly resolved by longer baking of the sand cores prior to casting to ensure the resin is fully cured and development work is continuing in conjunction with Darren Trigg at Resin Sands to modify the resin content of the sand. The surface finish was resolved by painting the cores with a zircon refractory paint but development in this area is also being done with trials in finer sands and modified machine profiles.