Pewter Stool

DIMENSIONS: 400w x 400d x 400h
MATERIAL: Pewter (92% Tin, 6% Antimony, 2% Copper)
PROCESS: Sand casting is one of the earliest forms of casting due to its simplicity and low-tech materials required. Sand casting produces metal components with a rough sand-like texture, often with a crude degree of accuracy, and therefore requires various finishing techniques to improve the surface finish. Such techniques include grinding, filing, hammer and shot peening, polishing and plating.

Molten metal is poured into a cavity mould made in either natural or synthetic sand, usually bonded with oil or chemical binders. Green sand is a mixture of sand, clay and pulverised coal bound with water to produce a green mould that needs drying prior to casting, to prevent the molten metal exploding. In industry, sand casting is typically just one of many process involved in the production of a single metal part. A master or pattern of the design is made by a patternmaker. The pattern is made slightly oversized due to the shrinkage of the metal that occurs during cooling. This is calculated using a measuring device called a shrink rule, appropriately scaled depending on the metal to be cast. The pattern must have a slight taper known as a draft angle on all vertical surfaces, to enable it to be removed from the mould without disturbing the sand. A conical shaped sprue is added to the pattern to allow the molten metal to be poured into the mould easily and for overfill. A riser is also added to allow for the escape of air when the metal enters the mould. The moulding box is made of two halves called the cope and drag. Sand is compacted into each half, the pattern is placed onto the surface of one of the sand boxes and the two halves are pushed together. The pattern is then removed leaving the negative cavity of the object within the sand ready for casting. Once the sand mould has been made, incorporating pattern, sprue and riser, the molten metal is poured into the cavity via the sprue. Once cooled the solid metal component can be removed.

My Pewter stool was made using a very simple form of sand casting. I chose to use the natural landscape of Caerhays beach[1] on the South coast of Cornwall to make the stool. Most of my childhood was spent on this, and other, Cornish beaches building castles, boats and tunnels in the sand, and I decided it would be nice to return to my favourite beach to produce a stool using a process Cornwall was once famous for.

During the mining boom, Cornwall had two of the World's three largest mine engine foundries (Harvey's 1779-1903 and Copperhouse 1820-1869). They were both located in Hayle, where the fine quality of the Hayle estuary sand was perfect for sand casting. Caerhays beach does not have the same fine sand as found in Hayle, but some areas of the beach boast sand of a consistent grain free of large stones or shells that would make carving an accurate mould impossible. The far western side of the beach is also completely below the sea during high tide, making the sand very well compacted, and remains nice and damp during low tide.

I had a portable twin gas cooker that I dug into a trench in the sand. By being below the level of the sand I could cover over the cooker with a wooden board to divert the wind and achieve the highest temperature possible. The 1kg pewter ingots[2], made by Geoff at Carn Metals in Pendeen, took about 10-15 minutes to melt at 236ºC in two of my Mum's old stainless steel saucepans.

Whilst the pewter was on the heat I sculpted various shapes and forms into the sand using simple tools such as a 10mm Ø metal rod, a small dibber used for planting seeds and a kitchen knife[3]. Once molten I poured the pewter into the moulds to see how easily it flowed into the cavity, and how intricate my patterns could be.

I spent the first three days simply discovering what I was capable of carving and what the sand was capable of being carved into[4]. I decided upon a three-legged stool with a triangular seat surface formed of sixteen tessellating triangles. I noticed during my experiments that when I dug a deep hole into the sand, due to the height of the water table dropping slower than the height of the tide, the molten pewter did not always reach the bottom of the hole. This would make four legs of equal length difficult to achieve, and so by making a stool with three legs, even if the legs were not exactly the same length the stool would always sit level on the ground without wobbling, even on an uneven surface. The seat surface is like a triangular mesh that achieves the largest sitting area with most economical use of pewter, saving both weight and money.

I began by marking out a 400mm equilateral triangle in the sand, divided each side into four sections and marked a line between each. By drawing a line between each corresponding mark on the opposite side of the triangle, the large triangular surface of the seat was divided into sixteen smaller triangles. I then took the 10mm Ø steel rod that I had prepared with a mark 400mm from the bottom, and pushed it into the sand at one of the three main perimeter corners of the seat until it reached the 400mm depth[5]. I pushed the exposed end of the rod towards one of the opposite corners of the triangle until the sand became compacted and resisted further movement, pulled it back and then pushed it towards the second corner as far as it would easily go. This movement gave the leg a natural taper and a v-shaped cross-section towards the top of the stool, making the leg inherently strong and as light as possible. I repeated the v-shaped hole for the other two corner legs and then began carving v-shaped grooves along each of the tessellating triangles of the seat with a knife[6]. I carefully carved out the sand from each channel to a depth of about 20mm.

I had to keep spraying the surface of the sand with a fine mist of water to stop the sand drying out too much and crumbling. Once all the triangular channels had been carved and the loose sand blown away, the sand mould was ready to accept the molten pewter. The process of carving the form of the stool into the sand took 45 minutes.

I removed the lid from the first saucepan and carefully poured the pewter into the mould starting in one of the legs[7]. Once the pewter reached just below the top of the leg I moved to the second leg and poured the pewter up to the same level. I repeated this for the third leg, then picked up the second saucepan and began pouring the slightly hotter pewter on top of the pewter in the first leg. The molten pewter began flowing along the channels and as the level of the pewter raised all the triangles connected. I poured until the pewter reached just below the level of the sand[8], causing a molten meniscus to form on the surface of the pewter.

After 10 minutes of waiting for the pewter to cool I began to excavate[9]. I dug with my hands[10] pulling the sand away from the triangular seat surface and the three legs until the sand held no resistance, and then lifted the shiny pewter stool out of its mould[11]. I had successfully sand cast a pewter stool on the beach.

Copper Stool

DIMENSIONS: 450w x 350d x 400h
MATERIAL: Nanocrystalline copper
PROCESS: Metal can be grown onto almost any substrate using a sophisticated electro-deposition process similar to electro-plating. This deposits nano-crystals of metal in an even honeycomb pattern thus ensuring there is no stress built into the metal and allowing the manufacture of organic metal shapes in one continuous piece.

Nanocrystalline metal is the strongest, most flexible form of metal achievable as the metallic structure is microscopic and entirely uniform. The virgin copper has no previous memory. Each copper particle is between 35-45 nanometers in size, approximately the size of 6 carbon atoms. Complete encapsulation of parts is possible with a metal coating as thin as 50 microns and as thick as time allows, and is an environmentally clean room temperature process that will not destroy the substrate onto which it is grown. This ensures metal parts are perfectly formed to the original object with no additional machining required.

The unique nanocrystalline structure makes the metal stronger in the curve than the flat, while remaining ductile at temperatures down to liquid nitrogen. The object to be encapsulated in metal is carefully sprayed with a fine suspension of colloidal silver in alcohol. The silver solution makes the object conductive and thus will attract metal particles when electrically charged. The silver coated object is then dipped in the electro-deposition tank containing an aqueous solution of 15% copper, 80grams per litre of copper sulphate and both organic and inorganic additions that refine the grain structure of the copper. The time spent in the copper solution dictates the thickness of copper deposited on the surface of the object.

My initial intention for utilising the electro-deposition process was to produce a piece of seating in expanded polystyrene - to literally hand carve either a stool or a chair from a block of material and then electro-deposit copper onto the rough bobbly surface. The idea being that once encapsulated in copper, the polystyrene core could either be melted or dissolved to leave a hollow metal form. The seat would be extremely strong, very lightweight, and have an amazing textured surface that makes reference to the nano-crystalline structure of the copper itself.

I worked closely with Ross Morgan of Morganic Metal Ltd. and we did an early experiment of electro-deposition on a miniature chair I carved in expanded polystyrene. The test revealed two main problems. The silver solution that is sprayed onto the object to make it conductive has an alcohol base that easily corrodes styrene, causing the delicate bead of the polystyrene to become pitted. This could be controlled using a very dry mix of the silver solution. The second problem, however, was less solvable.

Polystyrene is extremely light and buoyant, and in order to grow copper over the surface of the object it must be submerged in the electro-deposition tank.

The small test chair was easy to handle but a full sized chair in polystyrene would require a complex frame to give enough rigidity during submersion, and the current of the copper solution being pumped around the tank would cause too much movement of the polystyrene. The result would be a weak nanocrystalline structure and a copper chair without the incredible material strength normally achievable with electro-deposition.

It is necessary to use a material that displays sufficient rigidity to support its own weight, is non-buoyant or at least easily submerged, has a surface that readily accepts the conductive silver spray, and for my purpose, easily mouldable by hand using simple tools. Having played with the idea of using polystyrene due to its intriguing texture and potential to create hollow copper forms, I became fascinated by the possibility of producing a chair using a material that could be melted away once it had been encapsulated in copper. After much research I discovered a type of modelling wax produced by British Wax that is very hard and rigid at room temperature, yet at temperatures above 40º-50ºC becomes easily manipulable by hand. Best of all, the wax can be melted from the copper shell once electro-deposited and reused to model new pieces of furniture. As a raw material, it is infinitely renewable.

I began modelling the wax using my bath filled with hot water to make the wax mouldable. The hot water conserved the heat of the wax and made it easy to manipulate for long periods of time. I performed many different experiments using the wax[12], playing both with form and surface texture[13], all the time bearing in mind the process of electro-deposition and the strength characteristics of the nanocrystalline copper. My first full sized chair was a hand-made replica, from memory, of Gio Ponti's Superleggera chair of 1957[14]. I chose this chair due to its structural integrity and amazing lightness. My wax Superleggera had a very uneven surface, and almost childlike appearance.

The chair was incredibly difficult to construct due to the size of my bath. I had to build the chair in seven sections and then combine them together out of the bath when the wax was cold. The wax has no inherent structure when warm and yet can not be moulded together when cold. To create four legs, two backrest uprights and a seat surface in soft wax is impossible unless cold and rigid. So to join each section I had to heat the joint area locally using a hairdryer. This involved supporting all the relevant sections in position whilst heating the two pieces to be joined until they could be squeezed and moulded into one.

Though I liked the handmade, naive character of the chair I encountered structural problems with the design. The delicacy of the legs and uprights of the backrest could not support the weight of the heavy wax, and very gradually the chair began to slump. This could be disastrous when in the electro-deposition tank and thus I had to rethink my design. I decided a chair without the added weight of a backrest was a sensible option to pursue, especially when the cost of the process was taken into consideration. I proceeded to make a four legged stool in thick sheets of wax, with a pattern of holes for visual lightness and to give the copper shell additional rigidity.

I rolled out a flat sheet of wax in the bottom of the bath with a rolling pin, approximately 15mm thick. I used an old apple corer recently purchased from a car-boot sale to cut regularly spaced holes into the wax. The holes were arranged in a triangular pattern, similar to the way spheres pack together most efficiently, and I continued the holey pattern over the whole surface. Using the tap end of the bath as a mould I pressed two similarly patterned lengths of wax into two corners of the flat sheet so that two legs were created, each sticking up out of the bath using the corner radius as a form. Once moulded together and the overlapped holes neatened, I rotated the flat sheet and two legs 180º and repeated the process with a further two legs[15].

I now had an upside down, oblong stool with four gently curving legs, entirely covered in a pattern of circular holes.

I emptied the hot water and ran cold water over the stool to make the wax rigid. I carefully removed the whole structure from the bath and slumped it over a box whilst I carved a chamfer around all of the holes both top and bottom. I did this by rotating a scalpel around the edge of each hole three or four times to create a rough radius[16]. With over 400 holes this was a very time consuming process[17]. I then returned the stool to a medium hot bath to make the radius on each hole as smooth as possible using my finger.

At this stage I realised that a smooth surface could only be achieved on the underside of the stool as when in hot water it can not support its own weight when upright. To smooth the top surface the whole stool would have to be submerged in hot water and thus the stool would collapse. Unfortunately I learnt this the hard way. Upon near completion of my labouriously carved wax stool, and just one hour prior to delivering it to Morganic Metal for copper encapsulation, the structure melted when I placed it in water that was slightly too hot. My stool was irretrievably slumped at the bottom of my bath[18].

Three hours of sleep and a cup of tea later I began the stool again. This time I improved both the design and the process. The wax became 20mm thick, the legs wider and the holes fewer. I performed most of the moulding in my bath and once I had a seat surface[19] and legs[20] I moved to the kitchen sink. This is smaller than the bath, enabling all four corners of the sink to be used simultaneously, one for each leg. The radius around the edges of the basin are smaller, more proportionate to the scale of the stool, and also help to create stronger legs.

I placed the flat seat surface into the bottom of the sink with the edges wrapping slightly up the sides and then joined each leg to one of the corners[21-24], blending the wax as well as possible until seamless.

I used the apple corer re-cut the holes that had filled in whilst attaching the legs, then topped up the sink with cold water to harden the wax. To remove the stool from the sink I had to slide a scalpel blade and ruler between the wax and the side of the sink, as the hot water had firmly stuck the two together.

Once out and dry I had to cut away the impression of the plug-hole that had formed on the surface of the seat[25], and the process of carving the radius on all of the holes began again[26]. This time I used a variety of scalpel blades to make the job easier and neater[27-29]. Instead of submerging the stool in hot water to smooth the surface of the wax, as with my tragic first attempt, I used a hot air gun with a fine nozzle and a blowtorch to gently brush the wax with very hot air. All the ridges, bumps and imperfections melted and blended together to form a very smooth wax surface[30,31]. A few air bubbles had to be broken and filled with wax before the stool was delivered to Morganic Metal for electro-deposition[32].

A custom metal frame was built to accommodate my wax stool with two supports attached to the underside of the seat and a metal rod inserted into the bottom of each leg. Once wired up with the necessary electrodes and securely fastened, the entire stool was sprayed with special silver solution[33]. The frame was then hooked onto the bar suspended above the electro-deposition tank and the whole unit submerged[34]. The copper began to cling to the surface of the stool and grew in thickness very slowly, nanocrystal by nanocrystal.

Due to the current that forms as the copper solution is pumped around the tank, certain areas of the stool received a more prominent flow of copper than others. This causes the copper to develop in thickness quicker on the high profile areas than on surfaces concealed from the flow. The design of my stool was such that the areas that attracted a thicker layer of copper were also the areas of the stool where extra strength is required when sat on.

The feet, the outer face of the legs, the shoulders of each leg and the top surface of the seat are all areas that are subjected to higher levels of stress when the stool is sat upon. Thus the natural tendency of electro-deposition only benefitted the performance of my stool, building approximately 900microns of copper where it needs extra strength, and only 500microns where less stress is exerted. The electro-deposition process created a superbly strong, questionably light and surprisingly hollow copper stool. The holes decorating the entire stool provided thin supporting walls of copper between the inner and outer faces of the stool.

Once sufficient deposition of nanocrystalline copper had occurred the stool was removed from the tank. The supporting frame was cut away and the four holes in the underside of the legs were exposed. Gentle heat was applied to the base of the legs and the wax began to melt out, until all but a thin residue of wax lining the inner walls of the stool was extracted. This residue, in theory, was easily removable by submersing the stool in a tank of aqueous detergent for ultrasonic cleaning. In practice, this penultimate process proved catastrophic.

Electrical faults are impossible to predict, and unfortunately my work was the recipient of a rather serious one. A time switch controlling the length of time the tank was to run for had evidently seen better days, and in the middle of Friday night an electrical fire started directly above the cleaning tank containing my stool. The polypropylene tank and adjacent timber staircase began to burn. The tank collapsed spilling the aqueous detergent, and my almost completed stool was released into the fire[35].

At temperatures above 370ºC copper anneals making it very soft and pliable. My copper stool was heated to approximately 500ºC, causing the copper to distort, wrinkle and blister. Worse still, the nanocrystalline structure of the metal that had grown over 60 hours of electro-deposition agglomerated, becoming soft, ductile and malleable. The heat had irretrievably consumed all the nanocrystalline strength. Once again my stool of labour was ruined[36].

Two options lay before me; start building a third wax stool, or attempt to salvage the burnt remains of my annealed copper stool. With time against me the second seemed the only realistic route to take. The stool was sand-blasted to remove the burnt plastic and regain a bare copper surface that would accept a new layer of electro-deposited copper. A further 300 microns of copper was grown to 'case-harden' the stool and achieve its original strength.

The resultant stool has a highly irregular texture across the seat surface and two very blistered legs. I made the measured decision not to tamper with these unintended details, firstly due to the time required to remove them, secondly because they give the stool a character I could never have contrived, and thirdly because they occurred naturally, and concealing them would hide the inherent transparency of process so important to my work. My Copper stool is as it was meant to be[37,38].

SLS Stool

DIMENSIONS: 350w x 550d x 450h
MATERIAL: Laser sintered polyamide
PROCESS: A Rapid Manufactured stool based on a three-dimensional honeycomb tessellation of cuboctahedrons. The Selective Laser Sintering process allows the creation of extremely complex and accurate jointless structures impossible to reproduce using any other manufacturing process. The SLS stool exploits this potential and uses the structural efficiency of the hexagonal lattice created when identical spheres are packed together[39].

The laser sintering process can be described as 3D printing where the ink and paper is replaced with plastic powder, which a laser fuses together into a three dimensional object. The computer generated stereolithography (STL) file is sent to the Selective Laser Sintering machine and is built in hundreds of layers, one on top of the other, in a vessel of polyamide powder. As the laser beam traces over the surface of the powder, in the pattern of the computer model, it melts and hardens to form a solid object. After a single layer of powder has been fused into a solid slice of the object, a new layer of powder is spread across the surface and the laser traces the next slice, fusing it to the first. Looking closely at a laser sintered product, the very fine grain from the layers are apparent, similar to wood grain or the annual rings of a tree.

I made a variety of three-dimensional polygons in paper to explore the shapes in multiples, stacking and combining them in various configurations[40-42]. The cuboctahedron, made of 6 squares and 8 triangles was clearly the most structurally efficient and visually intriguing. I made a three-dimensional cuboctahedron of roughly the correct dimensions with all corners chamfered[43] thus creating an exact negative of the structure I was about to build on the computer. I then generated a cuboctahedron building block with 60mm edges and a 3mm diameter framework[44] on the computer. I duplicated this and stacked them to form a larger wireframe cuboctahedron[45]. Though materially weak the structural integrity of the cuboctahedron lattice produces a very strong stool.

The Rapid prototyping process relies solely upon ones ability to model digital objects using three-dimensional computer modelling programmes. During my interview at the Royal College of Art the Course leader, Ron Arad, asked which of the numerous 3-d modelling programmes I use for my design work, as though by default designers should be proficient in at least one. I had to admit my complete inability in computer modelling. I am still far from being an expert in even one 3-d modelling programme, nor even proficient, but I have succeeded in designing and building a complex geometric structure capable of serving its function using a programme called Rhinoceros.

I have learnt that such programmes 'can be' extremely useful during the design process, and in conjunction with additive-manufacturing and rapid-prototyping processes, can offer unimaginable design potential. I have also learnt that if there is ever something needing to be done beyond your own capabilities, there is always someone who is an expert in that field, often more than willing to help. Many thanks to Krish Girdhari[46,47] and Rob Phillips for your support. Thanks also to Colin Blain at 3-D Systems.

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