Aluminium Bronze Project

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1.Introduction

This project will look at various techniques in metallurgy and materials engineering to create a materials sampler that incorporates the following: anodized aluminium, heat treated, carburized mild steel, a dual-metal casting and a polyethylene and clay composite.

The material's sampler will be a small artistic piece consisting of four parts: flower, stem, container and fill.

- The flower will be cut out of aluminium sheet and that is anodized to coat and colour.

- The stems will be hand forged on a coke fire with decorative curls and scrolls; the steel will then be heat treated by quenching and tempering, then finally carbonized to prevent corrosion.

- The container is made of aluminium and copper; cast into a mould so that the composition elements solidify and diffuse only at the boundaries of the elements creating a bronze ring around the copper circle. The completed cast will then be machined into sheets and assembled into the container.

- When the flower, stem and container are complete, the stem will be held in place in the container while the polyethylene and clay composite is poured in and allowed to set.

This will effectively complete a piece that has the three material states: metal, ceramic and polymer.

This report is divided into four main parts beginning with background information on metallurgy, looking at crystal structures, diffusion and solidification, casting and treatment of the relevant metals. Information regarding the elements and alloy in the piece is presented and the report focuses on the microstructure of the ring of bronze.in the copper/aluminium cast. Next is a step by step construction method with relevant explanation of processes. Finally there is a discussion on the results, difficulties with comments on an artistic effect created with the aluminium cast and further research and experimentation is noted.

2.Background metallurgy

The following is a short explanation of basic metallurgy. It is important to study and try to predict results, however there is an over whelming urge to just try and see what happens and then go back and explain how it worked or did not. Several important metallurgical principals are relevant in this study perhaps the main concentration is on deforming temperatures, melting temperatures and cooling curves. Also keeping in mind this project is expected to be accomplished in a backyard forge area with only a coke based forge and household implements. Originally brass was a desired alloy but having read anecdotal experiences of zinc poisoning, this was decided against.

2.1 Crystal structure

There are seven crystal structure types the basic being the cubic structure. Within the cubic structure there are three types of atomic arrangement: face cubic centred (FCC) and body cubic centred (BCC). The FCC has a packing factor of 0.74 and 4 atoms per unit and the BCC has a packing factor 0.68 of 2 atoms per unit. This means the FCC cubic is the most efficient packing arrangement. Iron is an example of an allotropic element which means it can change crystal structures. Knowing these changes helps predict changes in strengths for deformation and strengthening purposes. The unit cell is one arrangement of the cubic structure and the atomic radii determines the size of the unit cell. The density of a material is the calculation of:

$$\text{Density} = \frac{\left(\text{number of}\frac{\text{atoms}}{\text{cell}}\right)(\text{atomic mass})}{(\text{volume of unit cell})(\text{Avogrado's number})}$$

Structural defects such as missing atoms called vacancies and dislocations (extra planes or twists) affect the mechanical properties of the material.

2.2 Diffusion

Diffusion is the movement of atoms within a material or between materials. This project specifically looks at the diffusion of one element, Aluminium into another, Copper and vice versa to create aluminium bronze. The temperature and the concentration difference influence this movement called flux. Adlof Fick (1829-1901) produced laws that describe the diffusion process. An energy called the activation energy is needed to allow the atoms to move to a new location.

Fick's first law

$$J = -D\frac{dc}{dx}$$

Where J is the flux, D is the diffusion coefficient and $\frac{dc}{dx}$ is the concentration gradient (Askeland & Phule, 2006).

The activation energy for aluminium into copper is 39,500cal/mol and the diffusion coefficient is 0.045 cm^2/s .The activation energy for copper into aluminium is 32, 270cal/mol and the diffusion coefficient is 0.647 cm^2/s (ASM online 2012).

When atoms of aluminium diffuse into copper or copper into aluminium the total flux is initially high because there are no copper atoms in the aluminium or aluminium in the copper but then as the concentration gradient reduces the rate of diffusion decreases.

The difference in diffusion rates suggests that that the copper will diffuse faster and further into the aluminium than the aluminium into the copper.

2.3 Solidification and Casting

Solidification begins with the formation of nano-sized crystallites called nucleation in the molten metal. The nuclei form at inoculation sites, in the cast iron pan used in this project there would be numerous impurities on the surface of the pan so heterogeneous nucleation would occur rapidly at the freezing temperature. The time taken to solidify is called the total solidification time. During this time the latent heat of fusion is released into the surrounding metal. In this project the thin metal casting (about 60mm thick) is being solidified in an open pan at room temperature so nucleation and solidification appears to occur almost instantaneously. Cooling of the metal still continues after solidification and the rate of cooling has some impact on final composition.

When molten copper is placed into a surround of molten aluminium and a temperature of around 1000°C is maintained, it is expected that the inner circle of the copper will being to solidify but the outer edge where it meets the molten aluminium will diffuse. When the desired effect is achieve the heat is reduce and the entire cast will solidify.

Alternatively a circle of copper could be heated to over 1000°C and molten aluminium added to the surround once diffusion between the copper and aluminium begins the melting or solidifying temperature of the alloy is lowered enabling further diffusion before solidifying.

2.4 Treatments

There are several ways to treat metals to strengthen them thus increasing tensile and yield strength. For this artistic piece the strength of the materials in the final product is not really relevant but the processes can help or hinder the fabrication and preservation of pieces of art.

Heat Treatment

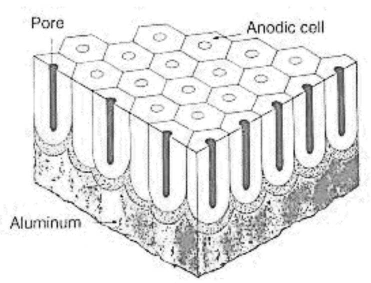
Quenching (rapid cooling) of steels with less than 0.2%C causes FCC austenite to transform to a BCC martensite. When working with hot steel quenching is sometimes practical to enable continuing to work on a piece however drilling assembly holes in components treated like this can become difficult and the component requires reheating or tempering to enable drilling.

Carbonizing

Carburizing is where the metal is heated in the presence of a high carbon content material such as charcoal. This method is usually carried out at around 900°C to 950°C and it strengthens the surface of the metal leaving the inner area more ductile. Having a higher carbon content surface may delay corrosion on the surface.

Anodizing

An electric current is passed through an acid solution thus forming an aluminium oxide layer on the aluminium, the acid then 'eats' pores into the layer and down also into the aluminium. Colour can be poured into the pores and then a sealant is applied. This creates a strong, scratch and corrosion resistant finish in attractive colours.



http://www.anodizing.org/Reference/reference_guide.html

3.Elements for project

3.1 Published Data Table

Element	Crystal Structure	Atomic Mass g/mol	Atomic Radius (A)	Lattice Parameter	Density g/mol/ cm^3	Melting Point ^0C	Shrinkage %	Valence
Aluminium	FCC	25.981	1.432	4.04958	2.699	680.4	7.0	+3
Copper	FCC	63.54	1.278	3.6051	8.93	1084.9	4.5	+1
Iron	FCC	55.847	1.269	3.589	7.87	1538		+3
	BCC		1.241	2.866				+2

3.2 Iron

Iron changes from ferrite BCC to austenite FCC at 912°C and then back to BCC at 1394°C (Askeland & Phule, 2006). Iron is alloyed with carbon to strengthen it (low carbon, medium and high carbon content). The amount of carbon reduces the temperature where the crystal structure changes and the carbon content allows for the possibility of heat treatments. Low carbon steel can be plastically deformed by heating above the critical temperature of 727^{0}C (steel is glowing red). Forge welding needs a temperature of about 1200^{0}C (steel is light yellow, almost white).

3.3 Aluminium

Aluminium was first produced around 1854 despite earlier attempts to extract it from its Bauxite ore. It is very light; about one third the density of steel and this property has meant its application in the making of vehicles successful because of greatly reduced fuel costs. Aluminium is highly conductive of heat and electricity and is resistant to corrosion due to the protective layer of oxide that forms instantly on the surface.

3.4 Copper

Pure copper is ductile and malleable; it can be rolled into very thin sheets and drawn into narrow wire without cracking. Copper is highly conductive of heat and electricity, it can easily be welded and is corrosion resistant.

It can be strengthened by alloying, but this offsets its conductivity. Copper and its alloys come in a variety of attractive colours.

3.5 Aluminium Bronze

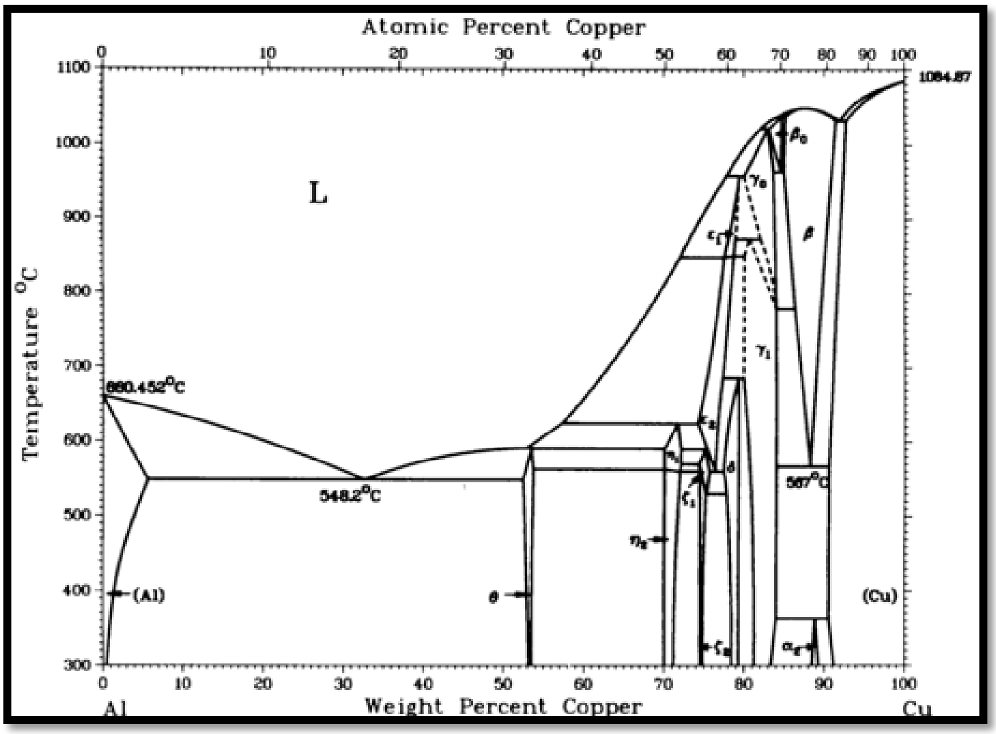
Bronze is an alloy of copper and tin but can also be copper with aluminium usually up-to about 14%Al. Iron and nickel are added to create a stronger alloy. Aluminium bronze has a useful property of being non-sparking and is an aesthetically pleasing colour.

3.5.1 Phase Diagram for Aluminum Bronze

The following phase diagram shows the alpha and beta phases of aluminium bronze in relation to copper to aluminium ratio. The freezing point rapidly decreases as more aluminium is diffused with the copper.

Up-to 8%Al there is a single α phase and then >8%Al there is a α + β phase which is stronger than the α phase but less ductile. According to Alexander and Street (1960) aluminium bronze is un-usable for engineering purposes between 16% and 88% aluminium or 12% and 84% copper in relation to the phase diagram below, except for a 50-50 hardener intermediate alloy. The crystal structure is currently unknown at γ_0 77.8% to 84% and β_0 83.1% to 84.7% (ASM 2012).

Al-Cu (Aluminum - Copper) Phase Diagram
J.L. Murray, 1985 ASM International 2012



4.Construction of Materials Art Sampler

4.1 Flowers

Cut 4 or 5 petal shapes from aluminium sheet with 8mm hole in centre for stems and anodize the petals various colours. While this is a practise that can be achieved at home there is access to a commercial anodizing business locally so this will be utilised, on this occasion, due to time constraints.

4.2 Stems

Light the forge and heat a piece of 8mm 1020 steel round to a red heat and draw down end. Reheat and hammer scroll the end; this can be put in the charcoal bucket to carburize to help prevent corrosion.

When cool, stick the stem through hole in flower with scrolled end on the topside and solder the underneath.

4.3 Container

Light the forge, getting the fire going with wood and charcoal. When hot, place a cast iron pan on heat, put in a steal pipe to make the hole for the copper. Melt the aluminium around the pipe and when liquid, place pan off the main heat but keep at a liquidus temperature (around 700^{o}C).

Place another cast iron pan onto the hottest part of the fire and place in copper wire. When copper is liquid (being mindful that the cast iron pan will melt at >1500^{o}C) remove pipe from aluminium melt and quickly put first pan on hottest part of fire and pour liquid copper into the hole in aluminium melt.

Leave pan on heat but turn off forge air allowing the pan to cool slowly, facilitating diffusion in bronze ring zone. Some agitation of the pan may be necessary. When cool either smooth with grinder or leave with wrinkly finish. Do this four times for four sides and use plain aluminium melt for base. Cut into squares and diffusion weld sides to make up container.

4.4 Fill

While this step is irrelevant to this metallurgy course it is an extension of an investigation of polyethylene fusion, quenching and compression hardening testing done in a previous project.

5.Results and discussion

Despite repeated efforts the bronze ring was not created. A better crucible and refinement of technique is required. No information was available on the production of similar castings.

Aluminium is relatively easy to melt on the home forge and casting into moulds made of green sand or using lost wax method are real possibilities. In terms of artistic effect, the quick forming ‘skin’ of oxide on the solidifying aluminium can be agitated to create a wrinkly effect which could well be a desired result.

6.Further investigations

Once the bronze ring is produced it can then be analysed using a metallographic microscope to study the composition. The crystal structure is unknown in a couple of phases of aluminium bronze and this could be investigated.

A broader area of investigation is the calculation of the amount of energy required to produce this sampler (not including the energy to produce the aluminium and copper in the first place.) This would require the amount of coke to be weighed and the energy used calculated and added to the energy used in the anodizing process.

7.References

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