Research into melting and casting of brass scrap for upliftment purposes

by M. Moseki* Paper written on project work carried out in partial fulfilment of B.Sc. (Eng.) (Metallurgy of Materials) degree

Synopsis

This paper presents the research into melting of scrap for job creation purposes in rural areas. The research was done on behalf of Mine Recycling Services (MRS), the company that will implement the project. The project involves the research into available cost effective and easy to operate technology. The paper covers the experimental and theoretical work that was conducted. The results were used to determine the best equipment and method for melting and casting brass scrap.

Objectives

The main objectives of the project are the following:

- ➤ Selection of cost-effective and easy to operate technology and equipment
- ➤ Economic evaluation.

Theoretical research

Melting

Various furnace options are available to melt the brass scrap. The choice between the many methods depended on the costs (initial and running) and the ease of operation. Research was conducted by contacting people in the know (Suppliers, foundries etc.) concerning the available methods, the advantages, disadvantages and, most importantly, the costs. The fuel source was the more important information—this was a toss up between LPG, coke, and paraffin.

Coal-fired furnace

For this type of furnace shown in Figure 1, the crucible is surrounded by coke, which in turn is surrounded by an open furnace built by bricks. The furnace is simple to build and all that is required is refractory bricks, wire and metal rods. It is a cylindrical structure that surrounds the crucible. About 10 cm from the floor is a grid and a stone (stand) on which the crucible is placed. The coke is placed above the grid surrounding the crucible. As the coke burns, it forms hard lumps (clinkers) and ash. These do not combust. To remove this, the coke is poked every 10 minutes with an iron rod. The hard lumps are forced below the grid into the chamber below the grid. As the coke level drops, more coke has to be added.

There is an opening at the bottom of the furnace, which allows the flow of air into the furnace. The furnace is designed such that the air enters at the bottom and rises up the furnace through the coke. The aim of introducing air is to increase the air concentration, which in turn increases the temperature that is attained. An industrial fan can supply the air. The brick furnace can last for about 5 heats. The first charge to melt takes about 90 minutes but the next ones take about 30 minutes.

Gas-fired furnace

The combustion of gas is the source of heat in this furnace. The gas is combusted using a gas burner in which gas is mixed with excess air to ensure complete combustion of gas. Air and gas are fed to the burner by means of fans and control valves are used to control their flowrates. The combustion products (normally CO_2 and H_2O) circulate in the furnace thereby heating up the crucible in the furnace. The fuel can either be natural gas (Natal gas, Sasol gas, etc.) or Liquid Petroleum Gas (LPG). The gas can be supplied in gas cylinders. The problem with using gas is that large flowrates are required in order to attain 950°C. As a result 6–8 large cylinders of gas have to be connected to fire the furnace. A brick set up, as described for the coke-fired furnace, can be built to house the crucible and the burner.

Paraffin-fired furnace

For this type of fuel source, a paraffin burner

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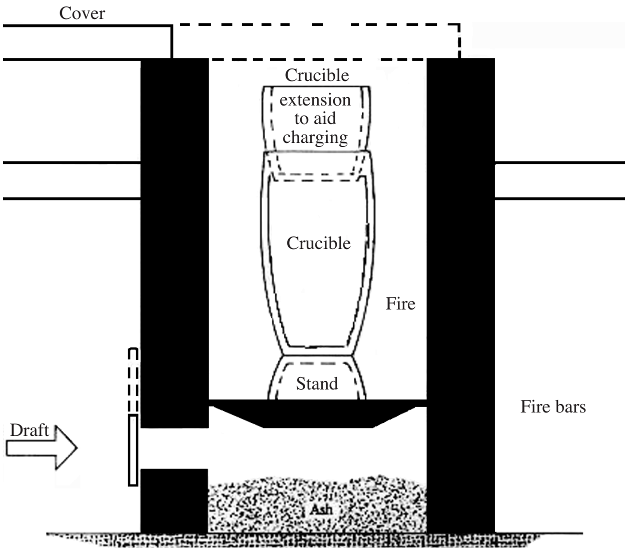

Figure 1—Typical coke-fired furnace

can be purchased for the application. It consists of a little paraffin tank connected to a motor and then to the burner. The motor needs to be run by electricity and will probably require maintenance at regular intervals. As with the gas-fired furnace, a similar set up to that used in the coke-fired furnace can be built out of bricks to house the crucible and the burner.

Casting

Either investment casting (i.e. the lost wax process) or sand casting can be used for casting the brass. From the theoretical research that was conducted, it was concluded that although the investment casting process offers greater flexibility than sand casting, it is time consuming.

In the lost wax process, the wax pattern has to be made from wax initially. The pattern can either be moulded directly or can be made from a negative (using e.g. fibreglass). However, both methods are time consuming and the pattern has to be made every time for each casting.

Furthermore, the investment (e.g. clay, plaster of paris, and gypsum) needs to be fully dried and this takes a couple of days in a kiln/sun. In short, the use of investment casting seems to be more complicated and time consuming. On the other hand, sand casting is very quick and is simple. For these reasons, sand casting was chosen and sand castings were experimented with.

Practical research

Melting

Melting was conducted on samples similar to that which will be used i.e. assorted old (i.e. obsolete) brass scrap. The aim being to assess the difficulties associated with melting the scrap. The following tests were conducted:

- *Elemental composition of scrap and cast products.* This was conducted by the use of an atomic absorption (AA) machine. Tests were conducted in order to accurately monitor the compositions of the two most important alloying additions, namely zinc and copper
- *Determination of melting losses (general)*. Upon melting, a lot of material is lost by volatilization. In order to appreciate this, a known mass of material was melted and the mass afterwards was noted
- *Zinc losses*. A sample of the above-mentioned melted material was analysed on the AA to determine the magnitude of zinc losses
- *Ideal composition*. Theoretically, the ideal casting composition is at a 60/40 copper, zinc composition. Testwork was conducted in order to ascertain how to attain this composition
- *Prevention of losses*. Methods were experimented with to reduce zinc losses.

Casting

Once the material has been melted, it has to be cast into artifacts, which can be sold. The following testwork was conducted:

- Various artifacts were cast and their viability was assessed
- Experimental assessment of casting medium
- Variations in casting methods in order to assess the most efficient
- Compositional variations on the quality of casting. Similar castings were conducted using brass of different compositions in order to ascertain the best (in terms of mechanical properties).

Sand casting

In this type of casting, molten metal is poured into a cavity made in a refractory material to produce a casting. Upon solidification, the metal takes the shape of the cavity.

In foundries, where the surface finish of castings is critically important, the most common refractory material used for casting is silica sand bonded with a resin. Silica sand is mixed with resin and water is added. The resin is expensive and once the resin has been added, it hardens and cannot normally be reused. However, certain foundries have expensive plants, which burn off the resin, thus enabling the silica sand to be reused.

The above method is used widely in foundries due to the better surface finish that is obtained.

However, with sand casting the surface finish is not very good. More expensive options are available (e.g. some foundries import special sand from overseas at exorbitant prices), however, as the aim was to find the simplest and most cost-effective method, the above could not be used. From research, the sand that bests suits our needs is green sand.

Green sand casting

Green sand is a mixture of the following composition:

- 84% Silica sand
- 7.7% Bentonite (clay)
- 4% Coal dust
- 4% Water.

The 'green' refers to the fact that the sand is bonded by water and has nothing to do with the colour of the sand.

The above constituents can be bought separately and mixed to form the green sand. The sand can be mixed with a shovel as is commonly done with cement. The main advantage of this sand is that it can be re-used after casting (except for the burnt sand in direct contact with the casting) after adding 8% bentonite and 3% coal dust. The sand also tends to dry out quickly and so water will have to be added frequently. However, water composition is critically important and should immediately be mastered. If the water composition is too low, the sand does not bond and if the water composition is too high, the casting becomes heavy and renders the MgO, which is added to prevent the sticking of the two halves of the casting, useless. The silica sand that is used for this should be fine sand as these suite brass castings and imparts a better surface finish. The sand is compacted in wooden or metal boxes that are known as flasks. These flasks can be made in a workshop. The material that the flasks should be made from is either cast iron/steel or wood. Wooden flasks are a lot cheaper to make but have a finite life. Metal flasks are virtually indestructible but are heavier and a lot more expensive. Mostly, the compaction is conducted within the mould and as a result, the wood does not undergo much abuse. From the price difference, it is suggested that wooden flasks be used instead. However, the wood that is used should be hard.

Casting with different zinc compositions was also experimented with. At lower zinc compositions (~26%), it was noted that the molten metal was viscous and did not fill up cavities as well. The colour imparted was yellow, and the brass was reasonably soft.

At higher zinc compositions, roughly 45%, a red bronze-like colour was observed. The metal was a lot less viscous and filled the cavities very well. However, the brass was very hard and brittle resulting in cracking during the finishing off. Shrinkage also seemed to occur at these high zinc compositions. At a zinc composition of slightly less than 40%, the properties were ideal. The metal was viscous enough to fill all the cavities, the final casting was not too hard and no shrinkage cavities were observed. Figure 2 shows a 26% zinc casting. This casting shows cracks and the viscous nature of the brass resulted in the mould not being filled. Figure 3 shows the difference in colours between a low zinc brass artifact and a higher composition brass component. Figure 4 shows the shrinkage that was observed at higher zinc compositions (i.e. greater than 45%).

Patterns

One of the main advantages of using sand casting is that the pattern can be reused (unlike in investment casting). The patterns are normally made out of wood (Figure 5), metal (Figure 6), etc. and are of the shape of the final article to be cast.

The patterns can be made of any rigid material but wood and metal are the most common. Wood is soft and patterns can easily be made. However, the wood has a finite life and tends to break, crack, etc., after a while. Patterns can also be made from metals. In this case, making the pattern is quite time consuming. However, the pattern lasts for a very long time. Softer metals such as aluminium are the best for this application. Whatever the pattern is made of, MgO should be applied to the pattern to ensure easy removal of the pattern from the mould. Many patterns can be used to create a branched structure in order to ensure that as many objects can be made per mould that is made. However, not too many cavities should be made as the more there are within the same mould, the less stable the structure becomes. Also, the more cavities there are in a single mould, the bigger and heavier it ends up being.

A generous taper (~30°) should be imparted to the pattern (as in Figure 7). The reason for this is to ensure that the pattern is easily removed from the mould after compaction. However, the taper also adds an aesthetically pleasing effect to the mould. For flat plate-like patterns, holes

Figure 2—26% viscous Zinc casting showing cracks and cavities

Figure 3—Comparison of 25% (yellow) and 40% (red) Zinc cast artifacts

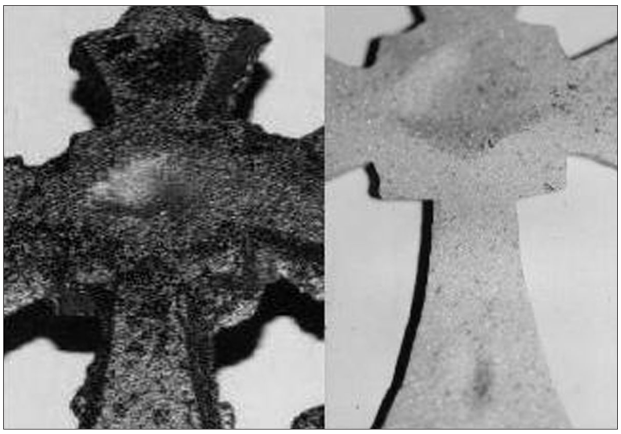

Figure 4—Two artifacts with Zinc composition greater than 40% showing shrinkage cavities (one in the as cast condition and the other after sand blasting)

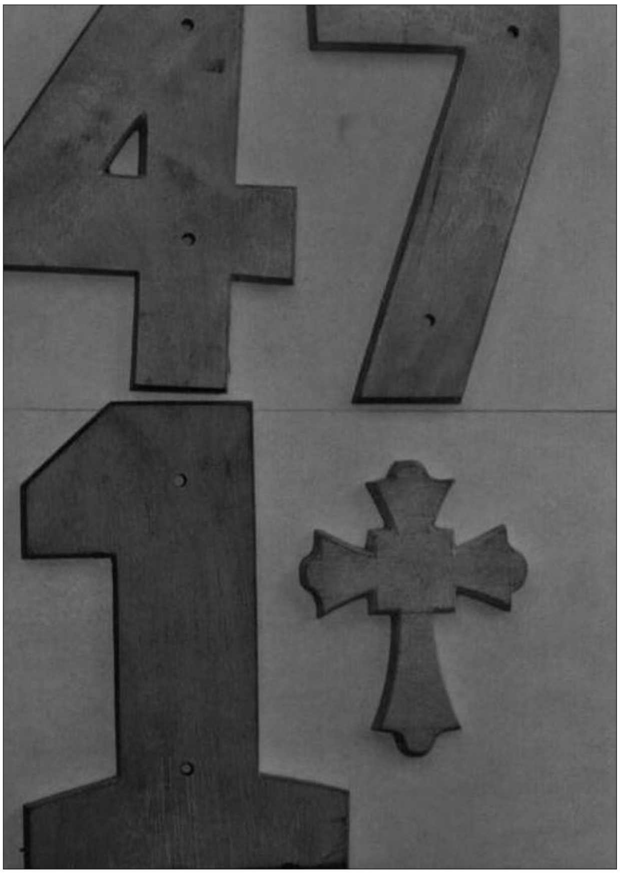

Figure 5—Various wooden patterns

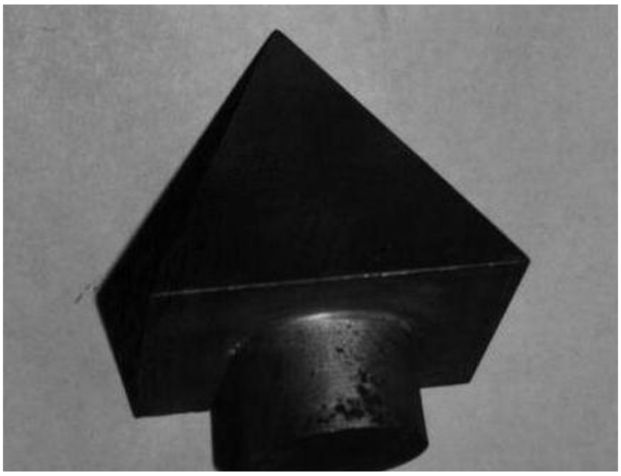

Figure 6—Metal (aluminum) pattern

should be provided for the insertion of screws. Once the patterns have to be removed, the screws can aid removal.

Finish

As mentioned earlier, the general finish obtained from green sand is not very good. A lot of porosity occurs on the surface and is not even. Although options are available to improve the surface finish by improving the sand, these are quite

Figure 7—Magnified view of wooden pattern to show tape

expensive and it would be more cost effective to simply finish the rough castings after casting. The following methods can be employed to finish off the artifact after casting.

- *Grinding*—An angle grinder can be used for this application. The grinding disc can be used to flatten the surface, round off edges, etc. A cutting disc can be used to remove the sprues, runners, etc. Angle grinders are not that expensive and neither are the grinding and cutting discs.
- *Sand blasting*—This involves imploding the surface with grit. The machinery can be purchased at a reasonably low price but compressed air is necessary. This limits its application in rural areas, however, the finish obtained is unique and sand blasting can often be used to mask the surface of a very bad casting. It is suggested that the sand blasting be outsourced. The School of Process and Materials Engineering offers a sand blasting service that only costs a 100 Rands a day. This equates to the sand blasting of approximately 50 small artifacts.
- *Acids*—This involves the use of concentrated acids and sodium dichromate. Various acids give the surface various different finishes.

  The most common is a three-stage process, which imparts a uniform colour and protective layer to the surface. The following are the three stages.
  - *Stage 1*—Pickling dip. This stage is to remove oxides and dirt that occur on the surface. It imparts a dull brown colour to the surface. The solution consists of 27–55% nitric acid. The immersion time depends on the concentration of the nitric acid. Once the surface of the artifact seems to have reacted with the acid, immersion should cease. Unlike immersion in the next two solutions, over-immersion in this solution is not a problem.
  - *Stage 2*—Bright dip. This solution imparts the original surface colour to the surface. However, it

does not remove some of the red copper oxide, hence the necessity for the final dip. The solution consists of 50–60% sulphuric acid (by volume), 15–25% nitric acid, a small amount of hydrochloric acid and water. The immersion time ranges between 5–45 seconds.
- *Stage 3*—Colour dip. The objective of this dip is to remove red copper oxide that occurs on the surface and to impart a protective layer to the surface of the artifact. The solution consists of 30–90 g/l sodium dichromate, 5–10% sulphuric acid and water. Immersion time should not exceed 30 seconds.

The final colour of the casting can also be varied by skipping one stage and/or altering the composition of the solutions that are used in any of the dipping stages.

Other alternatives are also available to alter the colour.

➤ Copper nitrate: this solution can be obtained by reacting copper with nitric acid. Upon application, it imparts a green colour to the surface. The best way of applying this solution is by heating the surface with a blowtorch and then by painting the copper nitrate onto the surface.
➤ Ferric nitrate: this solution imparts a brown to dark brown colour to the surface. It can be obtained by reacting iron (rusted nails, etc.) with nitric acid. The same method of application as explained earlier should be used.
➤ Potassium nitrate: this solution imparts a black colour to the surface. The same method of application as explained earlier should be used.

It is suggested that the following procedure be followed to impart a good finish on the cast products.

The use of an angle grinder with a cutting disc to cut off the sprue/runner and to round off the edges. The grinding disc can also be used to flatten/smoothen the surface of the artifact. Depending on the surface finish that is required, the products can either be sand blasted or pickled in acid. Often, the porosity that develops is quite deep and grinding the surface will not remove it. This porosity is also of a different colour from the ground , shiny surface. Sand blasting and pickling imparts the same colour/texture to the surface, which, in some instances, is beneficial.

The artifacts that should be made should be simple and most of them flat e.g. pyramids, numbers, crosses. The main reason for this is that flat surfaces can easily be cleaned with the angle grinder. However, smaller castings such as coat hooks can also be cleaned with an angle grinder. When using acids it is imperative that facemasks are worn and any work should be conducted in the open.

Economic evaluation

The aim of this economic evaluation was two-fold; to aid process selection and to determine the overall process costs (and hence the profitability). For these reasons, the capital (initial) and operating (running) costs have to be assessed.

Process selection

There was uncertainty as to the choice of firing the crucible: coke, LPG or paraffin. In order to choose between the three, the capital and operating costs of the various alternatives were compared. Coke needs a constant supply of air to be able to reach temperatures required to melt brass; an industrial fan is employed for this. The industrial fan contributes towards the capital cost account and the electricity used to run it towards the operating cost account. The bricks used to build the furnace structure and the coke are running costs, since the structure deteriorates after a few heats (i.e. every month).

The gas furnace requires a burner, gas cylinders and fuel. The burner and cylinders are capital costs while the gas fuel is an operating cost.

A motor runs the paraffin burner and paraffin is burnt to produce flame of high temperatures. The burner is a capital cost and the paraffin and electricity operating costs.

A summary of the costs is shown in Table I below.

Clearly, coke is the cheapest. The rest of the economic evaluation consisted of costing the various equipment and their operating costs. These costs are common to whichever furnace option that is chosen and can be added to the above to assess the overall costs.

Process costs

This involves the costs of casting, melting (covered in Table II) and finishing. The costs have been separated into capital and operating costs.

Under the capital costs, the following items are classified.

➤ **Crucible overheads.** These crucible accessories are tools that are used to clean and lift the crucible (tongs, ladles etc.), scrape off the slag on top of the molten metal and to add and mix the zinc into the melt.
➤ **Flasks and patterns.** These are for the sand casting and are made out of metal or wood. Metal (aluminium) patterns and wooden flasks have to be used.
➤ **Ramming rods, sprues, etc.** These items are for the casting process
➤ **Bentonite, coal dust, etc.** These items are for the green sand. An initial amount of the sand is purchased (capital cost) and a certain amount is replaced every month (operating cost).

Table I

Cost comparison between the different furnaces

Furnace Type	Capital Cost	Running Costs
Coke	399	524.3
Gas	1684	1426
Paraffin	4000	1078

Table II

Summary of economic evaluation (per month)

Capital Costs (General)	6456
Capital Costs (Coke)	399
Total	6855
Running Costs (Coke)	524.3
Running Costs (General)	4080.1
Total	4604.4
Items produced per month	392
Cost per unit Item	11.74592
Sales @ R30 per item	11760
Profit @ R30 per item	7155.6

- **The weighing scale** is to weigh the zinc and an angle grinder to finish the cast products.
- **Safety clothes,** is the final cost.

The following costs were classified under operating costs.

- Zinc and the brass scrap, which are the raw materials.
- The components of the green sand that need to be replaced.
- Grinding/cutting disks, hacksaw blades and files that need to be replaced when worn out.
- Acids and sodium dichromate for the acid cleaning process. These need to be replaced when no longer effective.
- The crucible, which lasts 50 heats, i.e. 50 cycles.
- MgO and borax powder which are used in the casting and melting sections.
- The artifacts can be sand blasted by an external source. It was assumed that 50 artifacts could be cast in one day.

In order to maximize the crucible life, the molten metal melted per 'heat' should be maximized. For the calculations, it was assumed that two people were working eight hours a day, 5 days a week. The first batch of metal to be melted will take about to 1.5 hours to melt. The first batch of metal takes longer to melt because the crucible first has to heat up before the metal inside can heat up. Subsequent melting times are shorter because the crucible is already at high temperatures. Including charging and cleaning of the crucible the subsequent melting steps should take 1 hour each. In an eight-hour day, seven 12-kg loads can be melted. With each melt, 14 artifacts weighing approximately 0.5 kg can be cast. Therefore 98 artifacts weighing approximately 0.5 kg each can be cast in a day. Therefore moulds with 98 cavities should be supplied for every melting cycle.

There are 2 types of boxes for compacting sand. The big boxes in which two artifacts can be cast and small ones in which only one artifact can be cast. For casting 98 artifacts, 32 big (with two cavities) and 32 small (with one cavity) boxes are needed. Sixteen boxes can be compacted in a day; therefore it takes 4 days to compact the required number of boxes. If melting is done on one day, and then it takes 5 days to complete one cycle of melting and casting, hence in a month there are 4 cycles. In one cycle, 98 artifacts are made, therefore 392 artifacts are made in a month.

Knowing how many moulds are needed, the amount of sand required can be worked out. The cost of first batch of the ingredients of green sand is regarded as a capital cost because the sand can be reused. However, bentonite and coal dust (binders for the silica sand) have to be added each time the sand is being reused. When molten metal is poured into the mould, green sand around the gating system gets burnt and cannot be reused. The sand that is lost has to be replaced. The cost of replacing silica sand, bentonite and coal dust in this case contributes towards the running costs of the plant. A bag of silica sand, 2 bags of bentonite and 4 bags of coal dusts should be bought every month.

Once the ornaments have been cast, a surface finish operation is performed on them. For this, an angle grinder, files and some acids are used. The angle grinder is a capital cost, but the grinding and cutting disks have to be replaced every month. The acids also have to be replenished.

When working with dangerous things such as furnaces and acids, safety precautions are imperative; hence safety clothes have to be purchased. These are included under the capital costs.

Table II shows the overall results of the economic evaluation. The cost per unit item, which was obtained by dividing the overall operating costs by the number of items produced, was worked out to be about 11 Rands. These items can easily be sold for over R30. For a selling price of R30, it is possible to make a profit of R7155.6 per month, which easily covers the capital cost of R6855.

It must be pointed out that this figure only applies when the operations are in full swing. Initially, the operation will be a little slow but after a while, it should speed up as the personnel become equipped and adapted to the work.

Conclusions

- Prior to the brass scrap being melted it has to be sorted. Big pieces should be cut down into smaller pieces and hollow pieces should be flattened. Copper (which is orange/red as opposed to the yellow colour of brass) should also be separated from the brass.
- The scrap should be melted in a coke-fired furnace. Coke was chosen as its initial and running costs are more than half the costs of the other two options (paraffin and LPG). The crucible to be used is a 12-kg clay graphite crucible. As the level drops more and more charge should be added. This can easily be attained by the use of a charging extension. Prior to melting, borax and glass should be added to prevent zinc volatilization. Just prior to casting, zinc should be added to get a zinc composition just below 40%. This is done, as zinc is cheaper than brass and an alloy of this composition casts well and has good properties.
- The molten metal is to be cast in green sand moulds. The sand moulds are in wooden flasks. The cavities in the moulds should be made with metal patterns.
- The surface finish obtained from sand castings is not very good and as a result, the castings need to be finished. An angle grinder should be used to cut off the sprues/runners (with a cutting disc) and grind the surface smooth (with a grinding disc). Acids can also be used to give the surface a shiny finish. Sand blasting can also be used to impart an even rough finish to the surface. ◆