19th Century Wrought Iron Manufacture in Germany

Photographs of Models Displayed in the Deutsche Technical Museum in Munich

These splendid models are displayed in a series of large cabinets which I saw on a visit around 2012. As you will see everything looks extremely life-like, and by photographing the models from different positions and enlarging portions of the pictures, one gets the appearance of movement.

I was most interested in the manufacture of wrought iron by the “puddling” technique. Here about 100-200 kg of pig iron is melted down in a small furnace, in contact with iron oxides and the excess oxygen in the combustion gases. The main effect is to oxidise the carbon in the pig iron. Accordingly, the melting temperature of the mass of material rises, until the whole lot becomes semi solid at around 1400-1500°C. One reason for this peculiar state is that the mass also contains semi-molten silicate based slag, this being derived from the combination of the silicon in the pig iron with iron oxides.

The mass is carved up, while in the furnace into “balls”, which are separately removed and then, while still at around 1500°C, the slag is squeezed out underneath a forging hammer.

Although there are many cross sections shown on the internet of the wrought iron “puddling” furnaces, as they were called, the one below is the only decent photograph, I know, showing an external view. It is of the iron works in Portrack, Stockton on Tees, known locally as the “Malleable”. My great grandfather was a puddler.

The tops of the chimneys can be closed by a movable flap or damper. This regulates the amount of air coming into the puddling furnace, controlling temperature and the oxidising capability of the atmosphere. This along with the use of iron rich oxides, was used to eliminate the carbon, silicon and phosphorous in the pig iron.

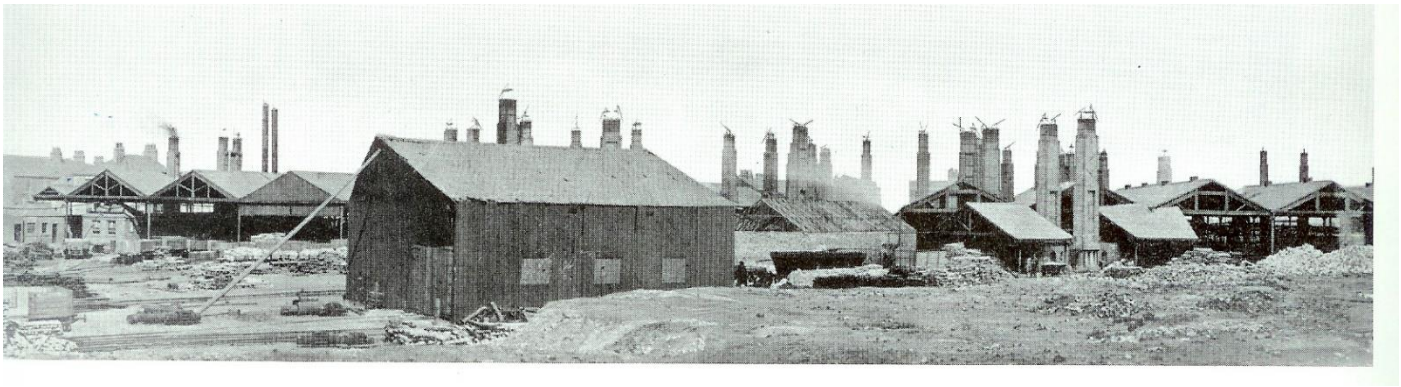

Fig 1: External view, Malleable Ironworks, Stockton on Tees

In the Munich Museum, I recollect seeing four cabinets, or displays relating to wrought iron. It was one of the best afternoons in a museum I can remember.

Fig 2: Display 1 ; View of one side of building which houses puddling furnaces and associated equipment

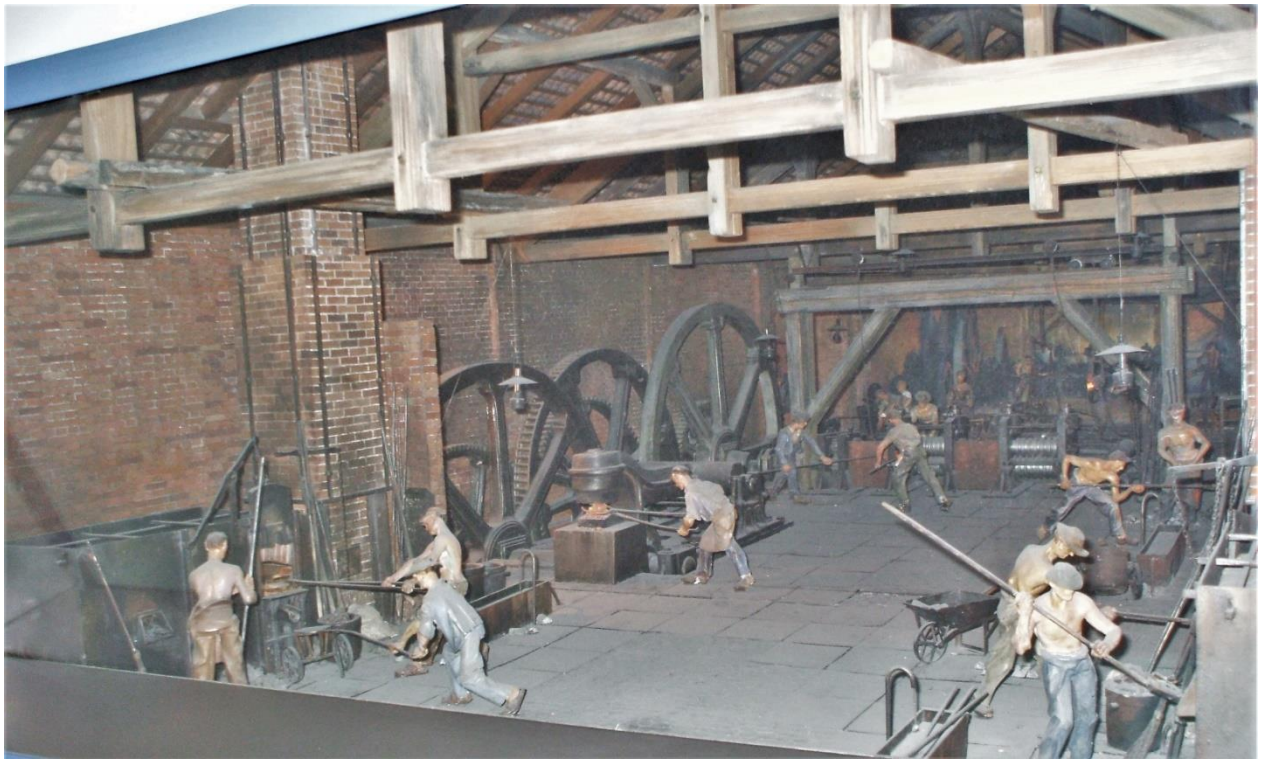

Fig 3 : Display 1 but showing there are furnaces on both sides

All of them are using the same processing equipment. This consist of a single forging hammer, almost in the centre of the picture, which is used to squeeze out the molten slag from the puddled ball. In the far distance can be seen two sets of rolls for making "Merchant Bar" for sale.

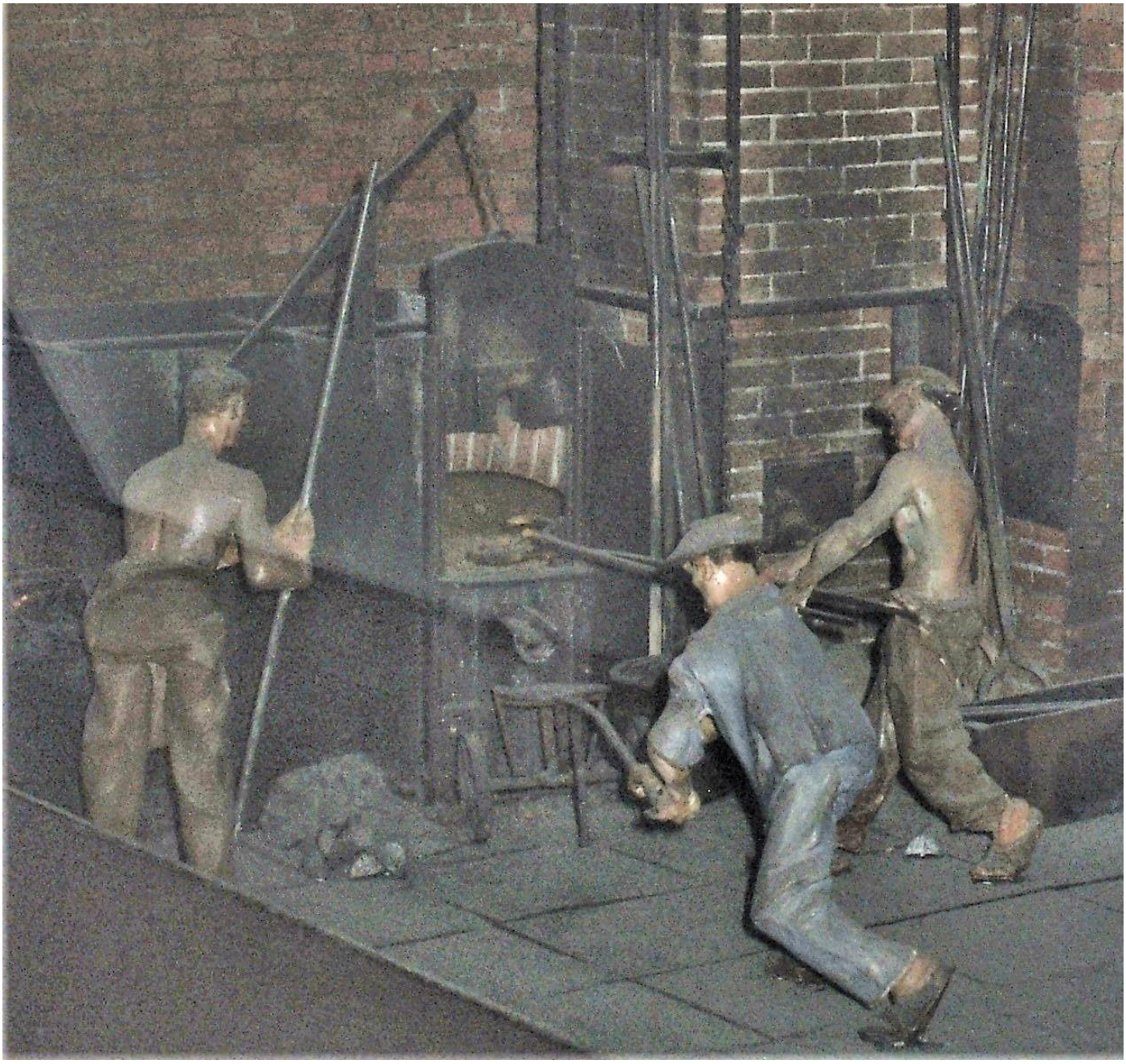

Fig 4 : Display 1, showing a close up of the three men working the furnace.

The one on the left is simply holding the vertical door open.

The one keeling is looking after a small ladle, on wheels. This will catch molten slag pouring out of the furnace. He seems to be the only one at all properly dressed. Perhaps the slag is tending to boil as it comes off.

His mate, I guess, is pushing a bar pig iron into the furnace. If I am right this is the beginning of the process, in which the first stage is to melt down the pig iron.

Fig 5 : Display 1 , showing the shingling hammer

Here the white hot puddled ball is being compressed to drive out most the molten slag using some sort of forging hammer. This was described as shingling in Britain. Unfortunately, it is not possible to see how the hammer is being driven, except that it seems to be connected to the massive gear wheels along the side of the building.

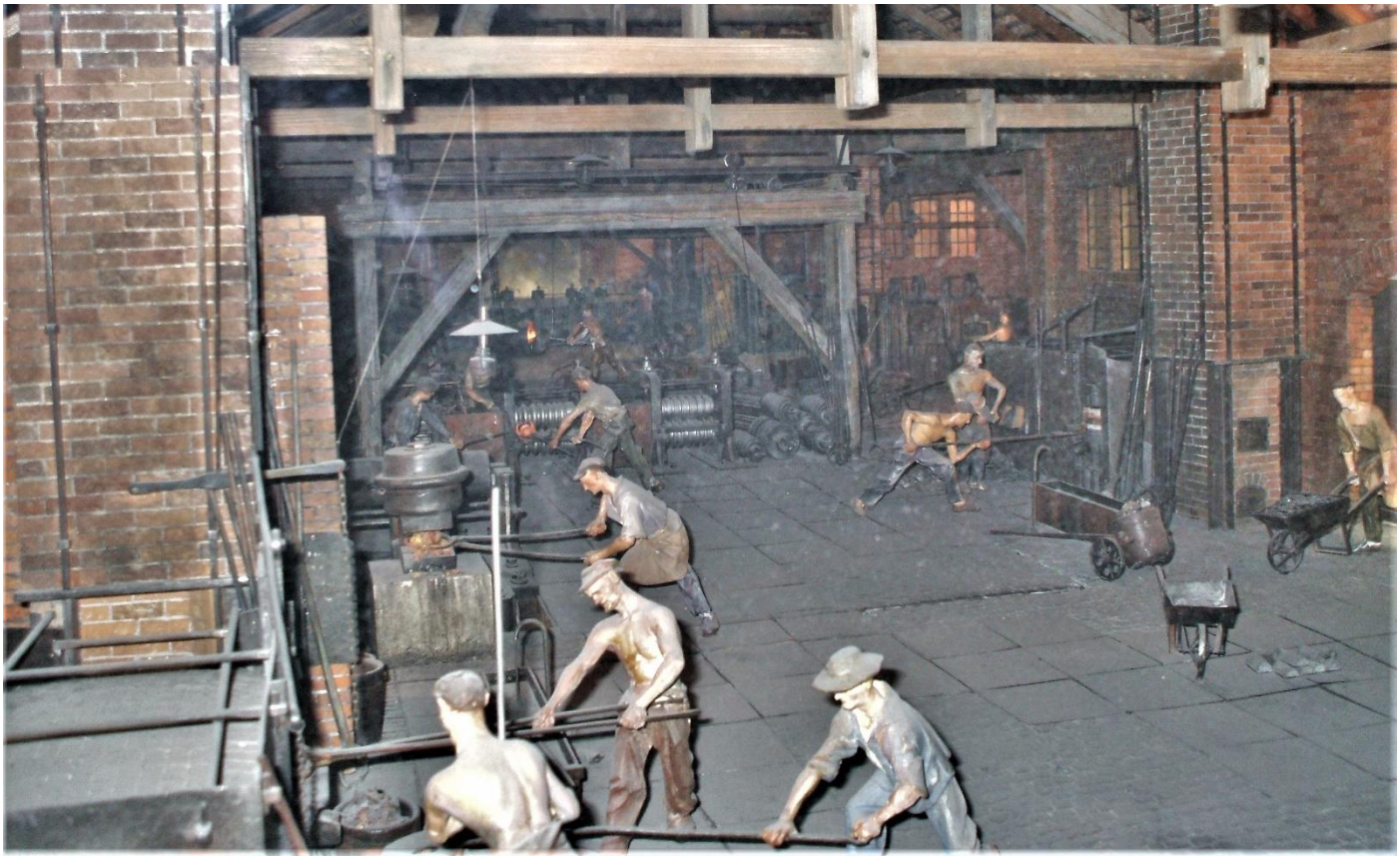

Fig 6 : Display 2 which might be showing wrought iron production at an intermediary stage

There are two interpretation for this picture, the question being "what are the three workmen in the foreground doing?

One suggestion is that they are rabbling the contents of the furnace, which is molten at this time. This brings the molten pig iron into contact with the air in the combustion products in the furnace and with iron rich oxides in the slag like mill scale.

The rabbling will also bring slag to the surface which will be trickling out into the ladle that the man with his back to us is looking after. In the original picture one can just see the red hot glow of the slag.

The other possibility is that this might be a puddled ball of wrought iron that has been pulled out of the furnace. On balance, I don't think so. That would be white hot, and in a well organised works, this would be being wheeled round to the shingling hammer. However, as can be seen, this is already occupied.

Fig 7 : Display 2, looking towards the back

Partly shielded by the man on the forging hammer are two men rolling down the wrought iron into square sectioned bars. This further squeezes slag out of the material. It looks like the mill is of the reversing type, and it is possible that the man on the left, underneath the light, actuates the reversing mechanism.

The cylindrical things, dumped on the right, by the unused rolling mill, are spare rolls

There are a set of furnaces at the far end which may not be for puddling, but used perhaps for heating material up for rolling, or any further processing. By altering the conditions, a crude form of steel, could be made, in principle.

Fig 8 : Display 3 showing the removal of the ball from the puddling furnace

In the final stage of manufacture, when all the carbon has been removed from the pig iron, the melting point is so high, that despite the temperature, the iron is solid although pliable. The slag which is mixed in with the mass is very soft and sticky. Imagine mixing dough, as in making bread, mixed in with honey or treacle, and you will have an idea of what the contents of the furnace are like.

In this semi-solid condition, the mass can be cut up into balls, each of which can be pulled from the furnace, where it will be taken to the forging hammer. This is what is going on here.

Fig 9: As above showing a back side view

Fig 10: Showing an enlargement from Display 3.

In Britain, at this point, the ball would be pulled onto a small two wheeled truck with a flat top made of iron. It would then be wheeled over to the hammer, where as much as possible of the slag would be squeezed out.

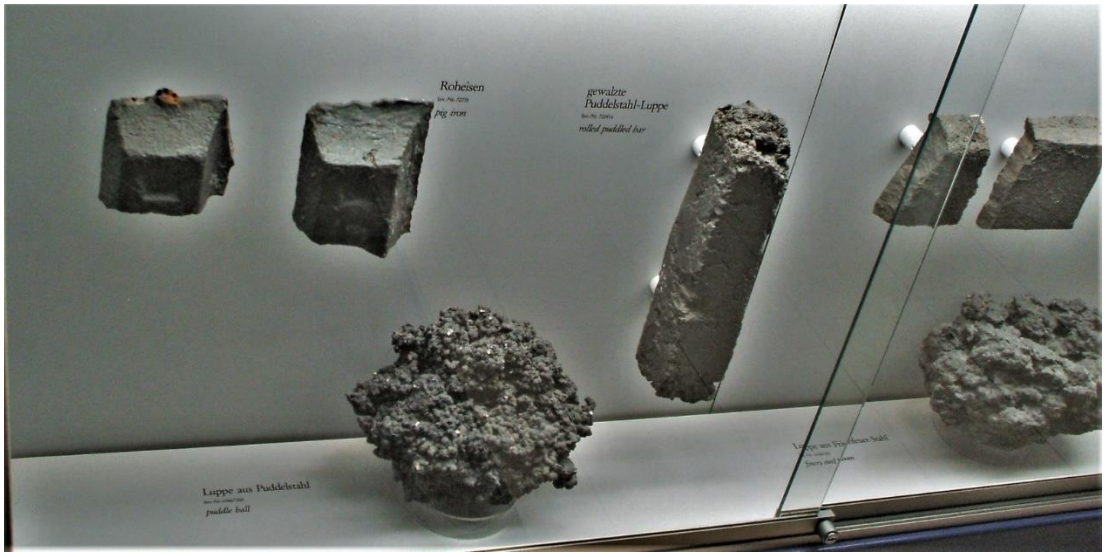

Fig 11: Display 4 : Showing pig iron and types of wrought iron

These are overall views of the display case. It is unusual to find examples of wrought iron balls and muck bar shown in a museum, even though tens of millions of tons were produced during the nineteenth century.

Part of the reason is that these were intermediate products that would be subsequently rolled down into bar iron for heavy forging, railway lines, angles (used in the construction of bridges and buildings) and plates used in the manufacture of ships, boilers and frying pans, etc.

Fig 12: Display 4 showing examples of Pig Iron, a Puddled Ball and a Muck Bar

Pig iron is a crude form of cast iron containing about 4% carbon and varying amounts of silicon, sulphur and phosphorous, depending on the source of the iron ores from which it was made. By the time the puddled ball has been made, these impurities have been eliminated. The main "impurity" in wrought iron is iron silicate slag, which when the wrought iron is heated up, prevents oxidation of the metal from interfering with any hammer or forge welding that need to be done.

It is apparent that the ball is composed of an assemblage of globules of iron will have been mixed up in the molten mass in the furnace. Part of the art of the puddler was to bring these globules together, before dragging them out of the furnace.

The muck bar is produced by rolling wrought iron, after much of the slag has been removed under the forging or shingling hammer. The oblong shaped piece would then be reheated, and passed through the rolls. This will squeeze out more of the slag. The muck bars would then have been "piled" together, then heated, forged and re-rolled to give a more uniform product.

Fig 13 : Display 4 showing examples of fractured pig iron and “steel” made by puddling

The steel shown here is not steel as we now know it, which does not contain any slag. Being made by the puddling technique, the main difference is that the carbon content is higher than that of wrought iron, which contains very little, circa 0.05%. The carbon content of steel, depending on its use will vary from about 0.2% up to about 0.6%. The higher the carbon level, the stronger the steel, but the less ductile.

These small changes in carbon content have a profound effect on the properties of wrought iron, mild steel, tool steel and cast iron. Something that can only be understood my examining the microstructure of these materials.

One other effect of the increased carbon level, is that the melting point of the globules will drop, by, perhaps, 100°C. The droplets will sinter or coalesce more easily. Accordingly, this ball of “steel” is much less irregular in shape.

This material would be intended for cheaply made tools, needing strength and hardness

The two pieces of pig iron are probably intended to show that pig iron, when it breaks, fractures without any ductility. I suspect they are from an earlier display comparing the material with wrought iron, parts of the display being lost.

Fig 14 : Display 4, Comparing Wrought Iron and Puddled Steel Balls

From distant memory, these balls were about 25-30 cm across. The close ups show that the wrought iron (top), was made by bringing together individual globules of iron, probably 1-2mm in size. These tended to agglomerate into larger irregular masses. The shiny flecks are probably particles of glass-like iron silicate slag

The puddled steel has a much more solid appearance. The higher carbon level would have resulted in some of the iron being present in a liquid form, this aiding the sintering of the globules.

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