ATOMISATION OF FERROALLOYS

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ABSTRACT

The process of atomisation is introduced and related to granulation. Some processes applicable to ferroalloys are discussed, along with their limitations and advantages. Examples of applications of atomisation to the processing of ferroalloys, including ferrosilicon and ferromanganese for use in the welding industry and as injectable additions to steel or cast iron are also presented. The economics of the process and the impact of process scale are discussed, along with criteria for process selection and system design.

1. THE ATOMISATION PROCESS

Atomisation is the breaking up of liquid into droplets (Fig 1). If a molten material is atomised into droplets, these normally cool rapidly to produce solid particles. Thus one could say that granulation and atomisation are conceptually identical, differing only in the size of particles produced. Granulation produces granules, which may loosely be defined as particles of the millimetre range (sometimes up to >10mm). Atomisation is normally taken, in a metallurgical context, to imply that the particles resulting are "powder" which can loosely be taken to mean substantially sub-millimetre range particles. In fact atomised metal powders are produced with sizes ranging from a few microns to a millimetre. Given that this spans nearly 3 orders of magnitude, the processes used to make and handle particles of the finer and coarser ends of this range are very different.

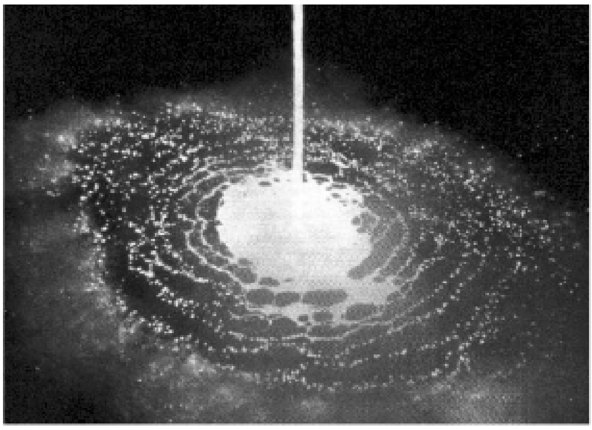

Figure 1. Break-up of molten metal in Granshot process (Uddeholm AB).

2. WHY ATOMISE (OR GRANULATE)?

Most ferroalloys and many other metallurgical products, intermediates and waste products arise from smelting processes, which produce molten materials such as ferroalloys, mattes, metals, or slags. Where these are finished (as opposed to intermediate or waste) products, they naturally have to be cooled down and transformed into a readily handled product before sale. For this, there are several options.

For brittle ferroalloys, mattes or slags, the most simple, if not always the most efficient method is dumping onto a floor to cool, followed by breaking up the resulting mass and crushing it to the size range demanded by the market. However, this concept has many drawbacks. Firstly it demands significant amounts of space and generates a lot of heat inside the building used. Water cooling by sprays is often used after pouring, and dangerous water/metal explosions are a common problem as well as pollution of the atmosphere. The cooled mass must be crushed and often it is found that a lot of unwanted fine particles are generated in the process, with low value and nuisance (or even hazardous) dust generation. Control of crushed particle size is not easy, and contamination by oxidation of the surface after casting and by slag is highly likely.

2.1 To produce a saleable, dust-free brittle product

Thus, while it can be argued that brittle materials can easily be handled in this way, modern environmental requirements favour a process that avoids crushing and goes directly from the melt to give a ~100% yield of smooth particles that can be readily handled with minimal dusting. There is now a substantial tonnage of ferroalloys processed into granules to avoid the problems of crushing.

2.2 To produce a small-sized ductile product

When dealing with a ductile alloy, which can only be crushed with difficulty, if at all, then pig casting is an option. However pig casting machines are quite large and complex, with fairly modest hourly capacities. A granulator can be cheaper to install and operate, more productive, and makes a much smaller product, which is often more easily handled in the markets (e.g. Nickel, ferro-nickel). As ferroalloys get less brittle as carbon content is reduced, atomisation is generally more attractive for low carbon grades.

2.3 To produce a reactive intermediate product

There are some smelted products that are not sold “as-cast”. Examples are mattes and intermediate alloys such as FeCoCu alloy (“white metal”) and other alloys for collection of PGMs from smelted catalyst residues for example. In these cases, the intermediate may need to be refined hydrometallurgically. In this case a fine particle size is very desirable; firstly to enhance reactivity while taken up into solution, and secondly to allow the particles to be readily suspended in the solution by stirring. In these cases, millimetre size granules are not fine enough. For instance in silver bullion refining, it was traditional to leach the Cu-Ag granulate (size 2~20mm) for 1-2 days to remove the Cu. With an atomised powder, a better result could be obtained in less than 8 hours.

Other flow sheets have been proposed including oxidation of atomised alloys with a volatile oxide-forming element such as W, Mo, V to separate it from other constituents by sublimation. The remaining porous oxidised cake can then readily be processed hydrometallurgically.

2.4 To produce a “rapidly solidified” product

Another reason for granulation or atomisation can be the rapid cooling rate involved. The biggest example of this is probably slags which, if cooled rapidly, can form a glassy phase that is useable as a cement. This can transform a disposal headache into a useful raw material. Integrated mining/smelting complexes can use the product to bond and stabilise mining waste backfilled underground. There is already a substantial volume of blast furnace and other slags used in this way, and pressure on the cement industry to limit it gigantic carbon dioxide emissions (currently one tonne per tonne of product, or over a billion t/yr globally at present) is already leading to increased interest in this option.

2.5 To produce special powder products

Finally there are demands for fine particles of some alloys for specific industrial applications. Examples will be discussed later, but include the welding industry and the dense medium industry. Improved flow properties due to spheroidal shape are one major selling point.

3. ATOMISATION PROCESSES

There are many different processes employed industrially for atomisation [1].

The major ones of interest in this industry are those applicable on a large scale (tons/hour) and include: -

- Water atomisation – using water sprays are pressures in the range from 10 to 100bars (exceptionally to 1000bars). Provides outputs to 30t/hour or more.
- Gas/air atomisation – using gas or air jets at pressures from 2 to 20 bars. Provides outputs to about 5t/hour.
- Centrifugal atomisation – using a spinning disk or cup at speeds from 500 to 5000rpm. Provides outputs to 100t/hour (e.g. for slag) but for sub-millimetre, perhaps 10-30t/hour.

3.1 Water atomisation

This is conceptually similar to water granulation (typically done at 2-5bars), but employs higher water pressures and a different operating geometry (figure 2). While granulation is well suited to handling huge volumes, as much as 5t/minute, such as might come off a launder when a furnace is tapped, atomisation is normally better controlled as the requirement to use several times the weight of metal as high pressure water means that pumping power would become extravagant at such rates. Also the demands on the dewatering and drying system become greater as the particle size gets finer. Where the next stage is hydrometallurgical, no dewatering or drying is needed, but for making dry powder products, the costs are significant.

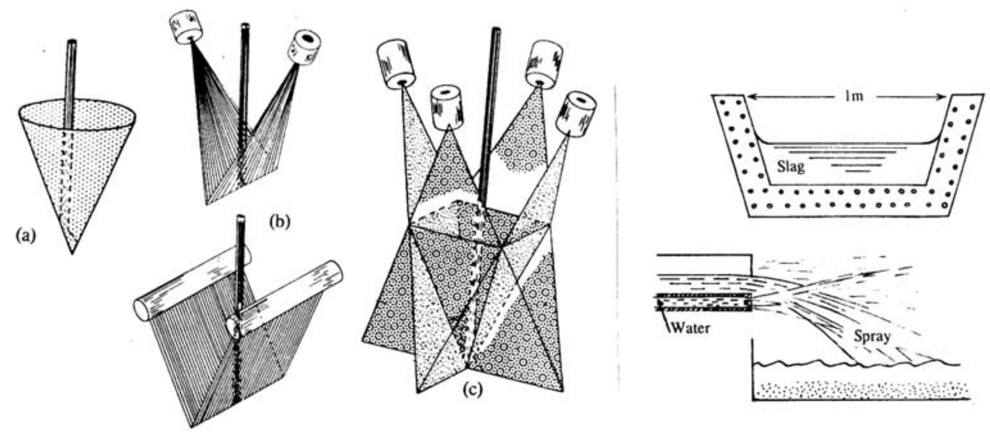

Figure 2. Water atomisation jets (a, b, c) and horizontal granulation for slag etc.

The pressures used depend on two factors. First the desired particle size, and secondly the characteristics of the melt. Thus sulphur-bearing melts, having low surface tension and viscosity, need much lower pressures than pure metals. To make an iron powder with mean particle size about 0.12mm needs about 70bars, and particle size is roughly inversely proportional to pressure. Thus a cast iron shot of about 0.5mm can be made at about 20bars pressure, but a 50 micron Ferrosilicon may need >200bars pressure.

In round figures, the water flow needed to cool ferroalloys is about 6L/kg. For lower pressure operations all of this will be pumped to pressure, but it is feasible for high-pressure operations to economise by only providing a fraction of this flow at pressure, with the balance introduced as LP cooling water. Thus a plant to atomise iron powder to about 70 microns at 30t/hour has a 1MW, 120bar centrifugal water pump (implying energy costs of ~30kWhr/t). However another plant producing 40 microns FeSi15 at 8t/hour only needed a 150kW HP pump even when operating at 250bars (implying energy costs of 19kWhr/t).

Water atomisation can be done in open air, or under inert gas. Obviously oxidation of the alloy will be reduced in the latter case. FeSi is relatively oxidation resistant and, even in open air, may only pick up about 0.1-0.2% oxygen. However FeMn is much more reactive and, even under nitrogen, picks up over 1% of oxygen (and liberates a correspondingly large amount of hydrogen in the process)

3.2 Gas/air atomisation

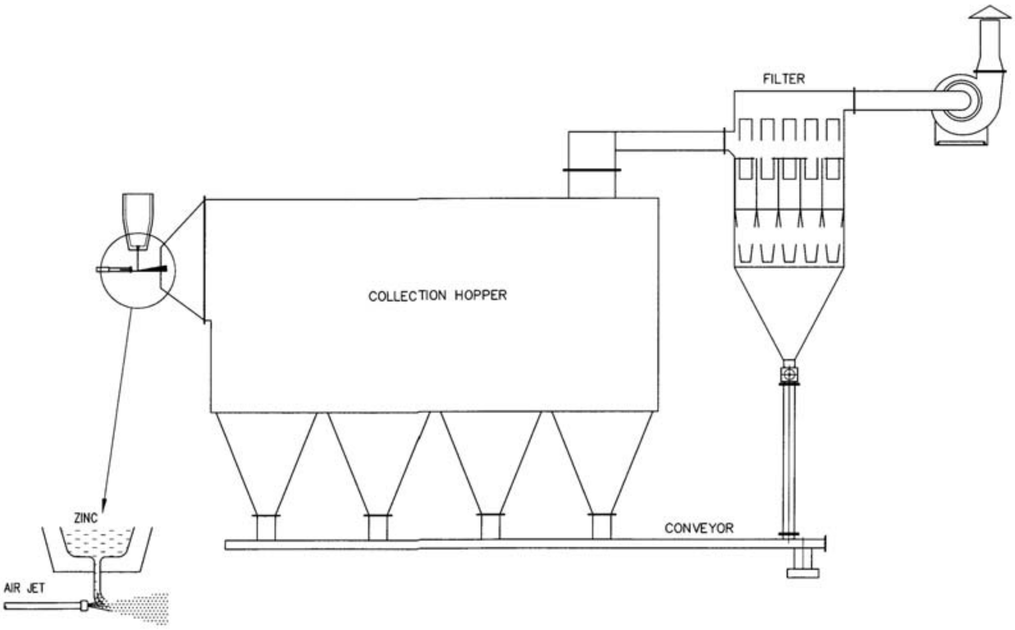

Figure 3. Horizontal air atomiser for zinc powder production.

This process, compared to water atomisation, makes a similar fairly broad distribution, and can make very fine powders. However it is generally necessary to operate more slowly than water atomising and the energy needed to compress the approximately one cubic metre per kilogram of gas needed to atomise is far higher than needed to pump water. Thus a plant to air atomise 2 t/hour of metal would require a compressor rated for 2000 n.cu.m/hr which at even 5bars would involve a compressor of over 200kW (implying energy costs of 100kWhr/t).

A drawback of air or gas atomisation is that cooling, compared with water, is slow. This means that large equipment is needed if freezing is to be complete before the spray contacts the surface. Thus while water atomisation/granulation can produce particles over a huge range from 10 microns to several millimetres, due to the slow cooling a dry gas process seldom makes sense for particles much bigger than 200-500microns. One way around this is to spray water into the system as well. This reduces vessel size, but adds the costs of dewatering and drying.

3.3 Centrifugal atomisation

This process uses the centrifugal force of a spinning disk or cup to form, first a film of melt and then droplets. It has been developed on a huge range of scales, from units for solder at less than 0.1t/hr using 30mm discs at 50,000rpm to dry granulation of slag at up to 5t/min using a 500mm disc at 500rpm. As in the case of gas/air atomisation, cooling after break-up is a problem, and it may be best to resort to water quenching for coarser particles. It has a big advantage in its mechanical efficiency, which is much higher than that of water or gas atomisation. For example a plant producing zinc powder of 200microns at 3t/hour used a 1HP motor, consuming less than 0.3kWhr/t.

Naturally, the material of the spinning disc or cup has a tough life. However even superalloys have been made by this method, using a water-cooled copper disc, so the production of ferroalloys in this way is probably feasible. Particle sizes are typically not very fine (say over 0.2mm), unless very high speeds, over 10,000rpm are used. Another major advantage is that it can produce much narrower distributions than gas or water atomisation. Thus excessive fines or oversize can be minimised.

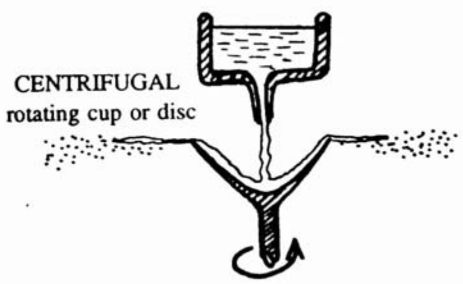

Figure 4. Centrifugal atomisation principle.

4. ATOMISED PRODUCTS AND THEIR MARKETS

Currently markets for atomised ferroalloys are somewhat limited and comprise <1% of the ferroalloy business. The following comprise both currently produced products and some suggested markets for future development.

4.1 Ferrosilicon 15% dense medium

In mineral and scrap metal separation, a suspension of dense powder in water can act as a heavy liquid and separate feed on a density basis. To allow separation of the dense medium from the feedstock, it is a magnetic solid, and to avoid rapid corrosion, it cannot be pure iron. Magnetite is the largest product in this market, especially for coal washing, but its low density limits application to mineral separation up to a density of ~2g/ml. Denser minerals need denser powder and FeSi15 is used. The largest part of the market is served by milled material, with angular shape. Due to its shape, the slurry viscosity becomes to high at slurry densities above ~2.6g/ml. For higher density separations an atomised spherical product is used and can operate as high as 3.5g/ml. Total market volume is substantial, perhaps 50-100,000t/yr, of which atomised product accounts for about 20-30%. Gas atomisation with nitrogen, steam or compressed air has been used, as well as water atomisation.

4.2 Ferrosilicon 45% for the welding industry

In the formulation of welding consumables to match various steels, the welding industry typically uses a dead mild steel wire, tube, rod or powder and coats, fills or mixes with it the necessary ferroalloys to ensure deoxidation and alloying of the weld metal. Fe45Si is often used in the coatings of manual metal arc electrodes, where it must not react with the binders used to make the extruded coating. It is found that crushed Fe45Si is too reactive and evolves gas, producing defective coatings. It can be passivated by heating to a high temperature in air, but a water atomised product has a passive film already (~0.1% oxygen) and also has spherical shape, giving good paste rheology. This market is probably in the order of 10,000t/yr, but changes in welding technology (e.g. tube-wire technology) may be changing powder specifications and volumes. Water atomised product has a significant market share.

4.3 Ferromanganese for the welding industry

In addition to Fe45Si, considerable amounts of FeMn are used in welding consumables. Here, atomisation has a less certain market. High carbon FeMn is easily crushed and milled, but lower carbon grades are increasingly difficult. Carbon levels in welding consumables are often low, but vary. Atomisation of FeMn with water results in considerable oxidation (~1-3% oxygen) which may be undesirable. Overall, the economics of this market do not seem clear-cut and while it may account for over 10,000t/yr of consumption, the amount of atomised product is small.

4.4 Injectables

In steel and iron production, the injection of alloying elements down lances has grown a lot in the past 20 years. It is normal to specify a coarse powder, e.g. 0.1-1.0mm for these applications. Some of these products, e.g. magnesium metal for desulphurisation of iron, are reactive so fines must be controlled. The process is used for making small additions, and can be used for trimming of analysis before continuous casting, control of superheat by injecting coolant, or deoxidation, inoculation etc. Metallic products used include magnesium, calcium, ferrosilicon, ferromanganese, sulphides and many others. Atomisation of these materials offers good size control (low dusting) and good shape (low wear and easy flow). This is an area of application likely to see solid growth in future as it offers excellent compositional control and low losses of reactive additions.

4.5 Higher melting alloys

While atomisation is in theory not limited to any specific temperature range, the difficulties of organising a controlled stream of alloys melting above 1600-1800C means that FeW, FeMo and FeV are not processed in this way. Unless a market emerges that demands spheroidal particles of these alloys, it is not likely to be profitable to develop their atomisation. FeCr is an intermediate case; it would not be too difficult to atomise, but the incentive to do so is not clear. Low carbon FeCr is not easy to grind and mill, and there may be some chemical applications for powders, but demand is not clear.

4.6 Silicon

A very large volume of silicon metal is consumed in the chemical industry. Obviously reacting it with chemicals demands an extended surface are, so powders are needed. The silicone industry makes silanes from it and has preferences for certain products of reactions that can produce a number of products. The catalysis of the production of preferred reactions by impurities in the silicon was of considerable interest in the 80s and it was thought that specific phases of impurity (of the type of CaFeMgSi) were precipitated during solidification, depending on cooling rate. Elkem constructed an atomiser for silicon, which was successfully operated on a tonnage basis, but it seems results of using the product did not justify the extra costs. It may be that the cooling rate was a little too high and granulation might provide a better performance.

5. ECONOMICS

One problem holding back the application of atomisation for the production of powdered ferroalloys has been, oddly enough, the lack of application of granulation. This leads to a lot of crushing being done, which generates large amounts of unwanted fines. These are a low value by-product and they are sold at a discount to lump size ferroalloys. However, if granulation is substituted for crushing, the amount of fines arising falls dramatically, so it is possible that this source of fines will decline in time. Also the properties of the fines are uncontrolled, and cannot easily be adjusted to specific market requirements. The particles are always angular (often very abrasive), often dusty (poor size distribution control) and may be rather reactive due to their clean surfaces. Atomised powders can be much better controlled in size range and are spheroidal in shape. They also often have high temperature oxide films that reduce reactivity.

Capital costs of atomising systems depend very greatly on the scale and type of product. For the case of a Ferroalloy in 10t ladles, atomised at a rate of 15t/hour to a fine, dry product (sub 0.25mm or 60#) we estimate a cost of $1.5M with output 60t/day (equipment and engineering only, excluding installation and buildings). This covers all equipment from pouring right through to drying and screening. Operating costs obviously depend on local rates so estimated consumptions are listed below with typical UK rates to give an example.

Direct labour - 1.6 man-hours/tonne	At $20/hour	$32/tonne
Energy - 40kWhr/tonne	At $0.08/kWhr	$3.2/tonne
Natural Gas - 360,000Btu/tonne	At $1/100,000Btu	$3.6/tonne
Other materials (refractories etc) -		$2/tonne
	Total	**$40.8/tonne**

To this should be added an allowance for material losses of 2-5%. At $800/t this is $16-40/tonne. Depreciation at 10% pa on $1.5M on an output of 15000t/yr is $10/t. Thus total process cost of less than $100/t is feasible. Capital costs follow normal rules, being related to the square root of capacity up to the maximum feasible size for single units. Operating costs fall rapidly, with labour costs per annum almost independent of output (highly mechanized equipment) while energy and gas costs only fall gently per ton processed. The above example is just processing one ladle every 4 hours; obviously higher outputs are easily achieved, but markets limit the need for this in many cases.

6. PROCESS SELECTION

The selection of the optimum process for a given product demands a lot on experience. Many factors must be considered including scale of operation, product quality demands, alloy reactivity etc. Unless the equipment vendor has previous experience of the precise alloy and product in question, trials of different processes are highly desirable. These both allow users to evaluate product quality, and allow the plant supplier to optimise production parameters (e.g. atomising pressure) to reduce equipment cost.

7. CONCLUSION

Granulation is widely used in the ferroalloy industry and experience is being gained in pouring ferroalloys in the necessary controlled manner. Atomisation is conceptually similar to granulation, but involves higher energy break-up of the liquid to make finer particles. These can have a number of applications and it can be expected that the development of atomisation technology and of ferroalloy applications will lead to a number of applications in the industry in coming years.

8. REFERENCES

[1] Yule, A.J. and Dunkley, J.J., "Atomization of melts " Clarendon Press 1994