GRANULATION METHODS FOR METALS AND FERROALLOYS *

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Abstract
Transportation and handling metals and alloys from mills to consumption factories as well as dosing in conventional processes with ingots and scrap has always been considered a complicated activity with high operating costs. Several manufacturers of ferroalloys willing to solve these problems have chosen an alternative for their products that can be used to secure, during transport and dosage in the processes to making special steels, with more efficient consumption of ferroalloys. The trend for the production and sale of ferroalloys is to provide the product in the form of granules packed in bags or in bulk. In this paper we will show you how the granulation process was developed and rapidly adopted the ferroalloys industry as an effective solution to reduce operating costs, create cleaner and safer working environments.
Keywords: Granules, shots, ferroalloys, pig iron, FeCr, FeNi, FeSi.

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1 INTRODUCTION

The large producers of special steels are consuming more ferroalloys in the form of granules, since a few decades, because shots are easy to manipulate and to add in the production processes. The granulation process might be applied to every type of ferroalloys and basic metals such as pig iron [1]. In addition, granulation process is very simple, does not require much operators and the operating cost is low compared to cast ingots form. Raw materials in shots can be packed and shipped in small quantities (2 tons' big bag) or in large quantities (containers 21 tons), for immediate consumption in special steel shops.

1.1. Objective

The main objective of this paper is to compile data on the existing literature related to the granulation processes, their evolution and development. To know also the main variables involved in the granulation process (metals and alloys), to obtain shots by pouring molten metal directly into a tank with water. In addition, to understand how granulation technology has effectively replaced ferroalloys in stone or ingots as raw material for the manufacture of special steels, in addition to promote safety and clean working environments for workers and reducing operating costs of production.

1.2. Literature review

Gold, silver, copper and platinum were generally found in rivers in the form of small granules. In ancient times, 2000 a. C, Granules of dripping gold, silver and others, were already obtained to make jewels and other tools [2]. However, with the increasing technological advances of the time in general, at the beginning of the twentieth century, the opportunity to use powdered or granulated metals is presented for application in the emerging automotive industry in order to manufacture small parts [3]. In 1937 Höganäs AB in Sweden, developed a new process to produce iron powdered, atomizing molten iron with pressurized water [4]. In May 1939, J. F. Ervin [5], achieved a patent I2 159,433, series No. 183,539. Current processes of granulation molten metals and alloys are developed after the 1970s.

2. PROCESS DESCRIPTION

The granulation process is a physical transformation from liquid to solid metals forming granules (shots). The molten metal fragments in the form of drops, fall into the tank with water and immediately solidify inside the cold water.

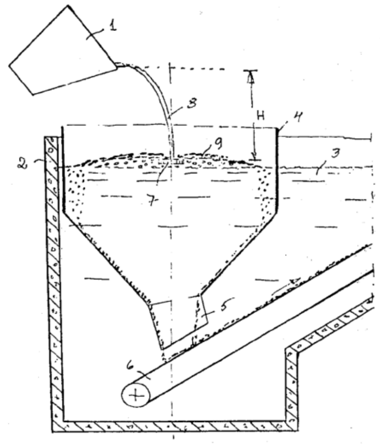
2.1. Methods for granulation molten metals

As we have seen, several methods have been proposed for granulation molten metals. The main difference between them is basically the way to fragmented the metal to form shots. The methods for obtaining the granules can be classified into:

1. Fragmentation molten metal by impact, out the water tank.
2. Fragmentation molten metal, whit stream water under water tank.
3. Fragmentation molten metal, whit stream water above surface of cooling tank.

2.1.1. Fragmentation molten metal by impact out the water tank

This method was proposed by UHT [6]. Granules are formed when the molten metal strikes a stone (Spray Head) and forms droplets that fall into the water tank and solidify. From the beginning the method produced good results. The granules formed are more uniform and with greater density. A hydraulic pump (usually, ejector technology) system removes granules from the bottom of the tank. Then, with other devices, dry them and pack them. Figure 1 shows the scheme of the method proposed by UHT to granulate metals and alloys.



Uddeholm patent. The liquid metal is poured onto a stone (7) where the stream of metal is divided into droplets.

Fig 1. UHT Method. Source: United States Patent N° 3,888,956

2.1.2. Fragmentation of the molten metal with a stream of water below the surface of the cooling water

After 1970s, several similar methods were proposed for granulating molten metals or alloys. The basic difference is the pressure of the ejector and the place where it is located in the tank, to fragment the flow of metal that falls into the water.

2.1.2.1. Showa Denko method

The method proposes by Showa Denko, consist to drop molten metal into a water tank. Inside the tank an ejector with high pressure water fragments the metal generating shots. Finally, a conveyor belt removes granules from de bottom tank to dry and packing. The figure shows the scheme of the method proposed by Showa Denko [7] to granulate ferrochrome.

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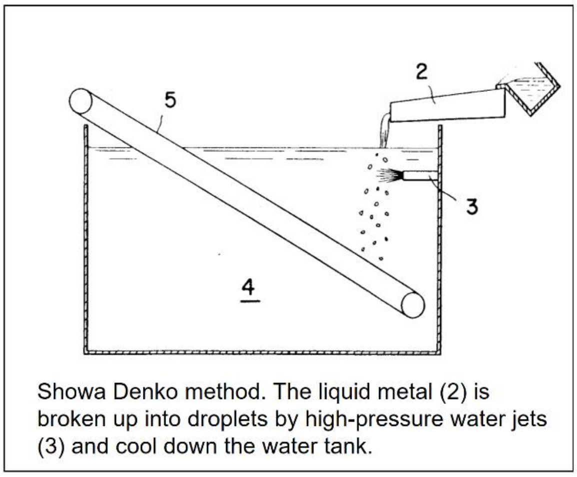


Fig 2. Showa Denko Method. Source: Y. Otani and K. Ichikawa.

2.1.2.2. Hyuga Smelting Co., method

The method proposed by Hyuga Smelting Co of Japan [8], dividing molten metal before falling into the water tank in two streams. The metal falls into the water tank and forms granules. A water pressure system, located on opposite side the flow metal, stirs and cools down water in the tank. The method was designed to produce ferronickel shots as raw material to produce stainless steel. Figure 3 shows the scheme proposed by Hyuga Smelting Co in its patent.

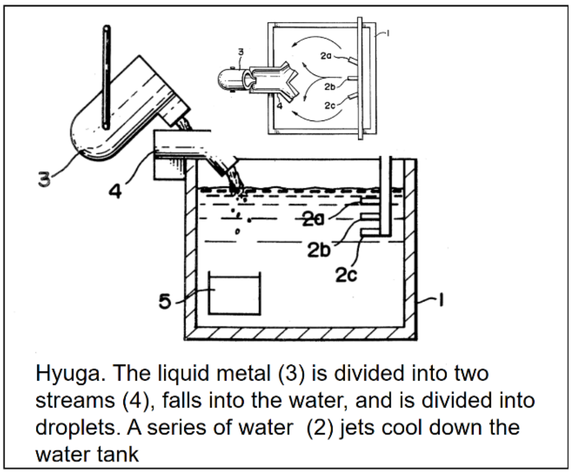
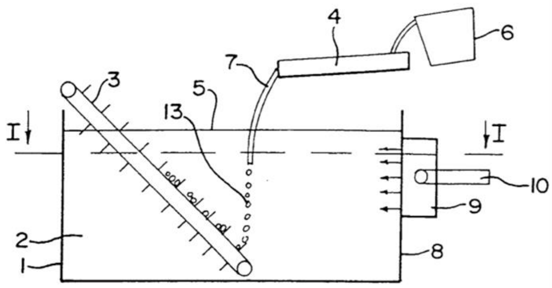


Fig 3. Hyuga Smelting Co. Source: United States Patent N° 4,172,673.

2.1.2.3. Método Elkem AS

The method similar to the above, consists of pouring the liquid metal into a tank with water. A low pressure jet water under the surface fragments the flow of molten metal that falls into the tank. The formed granules, 7 to 12 mm, are removed from the tank by means of a conveyor. Then, shots are dried and packed. Figure 4 shows the scheme of the method proposed by Elkem SA [9], for granular ferrochrome (FeCr).



Elkem method. Water is set into low-speed motion, which again breaks up the liquid metal stream (7) and droplets are formed (13).

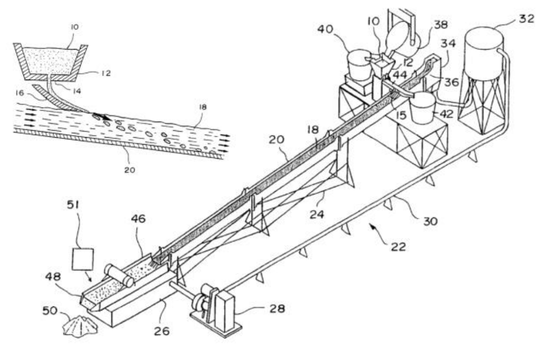
Fig 4. Elkem AS Method. Source: United States Patent N° EP 0 522 844 B1.

2.1.3. Fragmentation molten metal whit stream water above Surface of cooling tank

In this process molten metal pouring directly from a crucible through refractory channel and strike directly into water. Molten metal is fragmented by a jet water pressurized in order to form granules.

2.1.3.1. Mintek method

Mintek, an independent research and development company located in Johannesburg South Africa, also patents a method for producing granules [10]. The method called "Production of Metal Lumps and Apparatus Therefor" and consists of pouring molten metal into a stream water, where the granules form and cooling down immediately. Figure 5 shows the scheme of Mintek method to granulate ferrochrome alloy (FeCr).



The Mintek method. Shots (50) are produced by liquid metal (10) drop in stream of water (18) with the same direction water flow.

Fig 5. Mintek method. Source: United States Patent N° 6,287,362.

2.1.3.2. Kennecott Utah Copper method

This method proposed by Kennecott [11], molten metal (mate copper) before falling into the water, is fragmented by a jet water and immediately shots are formed and cooling down immediately.

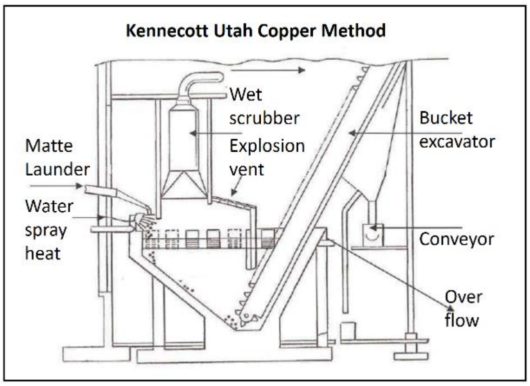


Fig 6. Kennecott method. Source: United States Patent N° 6,287,362.

2.1.3.3. Codemin Method (Anglo American-Brazil)

Codemin from Brazil [12], also developed a method to casting molten metal (FeNi) directly into a water tank. A cooling system supplies fresh water and removes the hot water from the tank using a pump installed for this purpose.

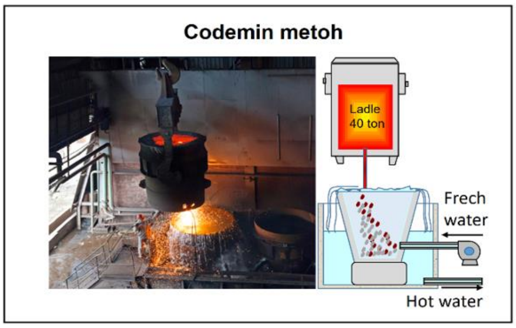


Fig 7. Codemin granulation method. Source: Jornal da Anglo 2009.

Presently using UHT technology [1], several pig iron producers are granulating excess production (pig iron), such as the Iscor Saldanha Steel plant in South Africa and Voest-Alpine Stahl in Donawitz, Austria (2004). Both companies with 120 tons per hour of capacity to produce pig iron shots. In June 2007 the SSAB Oxelösund plant in Sweden started operations with 240 tons per hour of capacity to to produce pig iron shots.

2.2. Metallurgical variables of the process

The main variables affecting the granulation process, associated to the shape and size of the granules, are related to metal temperature for casting, viscosity, surface tension and fluidity of the molten metal. Other variables of the granulation process are associated to the pouring rate, and the energy required to fragment the liquid metal.

2.2.1. Temperature of molten metal

As in all metal casting processes, temperature plays a very important role to fluidity and surface tension. Before casting, the temperature of the metal should be (40 to 50 ° C) above the melting point, to maintain molten metal fluidity, during the granulation operation. Pouring rate is another variable to control, the casting rate cannot be increased indiscriminately, due to the design of water cooling system in the tank. Water temperature in the tank should not exceed 75 ° C.

2.2.2. Viscosity of molten metals

Viscosity is the property that fluids have to move easily from one point to another. This parameter is very important during the metal casting operation, especially in granulation processes. If viscosity of molten metal is very high, the casting rate (granulation) decreases, and if it is low, casting rate increases.
Viscosity of all liquids depends directly on the temperature and chemical composition of the metals and alloys.

2.2.3. Fluidity of molten metals

Fluidity is the capability of liquids to fill mold cavities in any container. In the case of molten metals, the behavior is similar facilitating the pouring in molds. At higher temperatures the metals are more liquid. On the other hand, the impurities also directly influence the flow ability of the metals since these can raise or lower the melting point affecting the fluidity. This property promotes better formation of granules when the metal has good flow ability at temperatures between 20 and 50 °C higher than the melting point.

2.2.4. Surface tension of molten metals

The surface tension of metals and alloys is defined as the attractive energy between atoms to keep them grouped as a single body. The surface tension depends on the chemical composition and temperature of the molten metal. This property permits fragmentation of metal during the granulation process when the liquid metal strikes a solid body or directly when it falls into the water.

2.2.5. Chemical composition of metal or alloy

Concerning the proportion of the base metals forming alloy, no major changes have been observed; however, other impurities such as aluminum, silicon and sulfur affect the flow-ability and melting point of the alloys during the casting operation. This is a point that must be taken into account during refining metal process and give to metal the appropriate temperature before granulation operation.

3. DISCUTION

As already mentioned, the granulation process is very simple and the methods proposed show that its operation is relatively easy. With any method the goal is to fragment the liquid metal to obtain the granules.
However, we must keep in mind, that during the pouring metal into the water tank (T <30 °C), the energy transferred by the liquid metal to the water tank (T> 1580 °C) must be dissipated to prevent the water tank get hot. Then, the water in the tank must be changed continuously to maintain the thermal equilibrium and water does not exceed the limit (75 °C), pouring the metal at the previously calculated rate.
The energy to increase the water temperature is due to the expression:

$$Q_1 = m_{(water)} \times CP_{(water)} \times [T_{(f\ water)} - T_{(i\ water)}] \qquad (1)$$

where,

Q_1 = heat to be removed from the water tank
$m_{(water)}$ = mass of water
CP = heat capacity (water)
$T_{(f\ water)}$ = final water temperature (< 75 °C)
$T_{(i\ water)}$ = initial water temperature (<30 °C)

On the other hand, the energy to cool down metal from casting temperature (T> 1580 ° C) to below 70 ° C, is represented by the expression:

$$Q_2 = m_{(metal)} \times CP_{(metal)} \times [T_{(i\ metal)} - T_{(f\ metal)}] \qquad (2)$$

where,

Q2 = heat to be removed from the metal
M (metal) = mass of metal
CP = heat capacity (metal or alloy)
T (f metal) = final metal temperature (<75 °C)
T (i metal) = initial pouring metal temperature (> 1580 °C)

The thermal equilibrium in the system is achieved by controlling the output of hot water and the entry of fresh water into the tank, and maintaining a constant pouring metal rate. Concerning the temperature of the metal, it cannot be kept constant since at the time of granulation the metal is cooled due to the losses of the system.

3.1. Risks of explosions during granulation process

One of the main problems occurred during the first tests related to the granulation process is associated with explosions due to steam accumulation inside the tank and the generation of hydrogen by water decomposition by high temperature of liquid metal.

3.1.1. Explosion by steam formation

The temperature of the water in the tank cannot exceed 75 °C, then at this temperature the steam formation on the shot surface increase significantly. If steam is not removed, the risk to have an explosion increases due to steam mass generated in bigger [13]. Figure 8 shows a scheme where you can see the mechanism of shot oxidation and steam formation in the water tank.

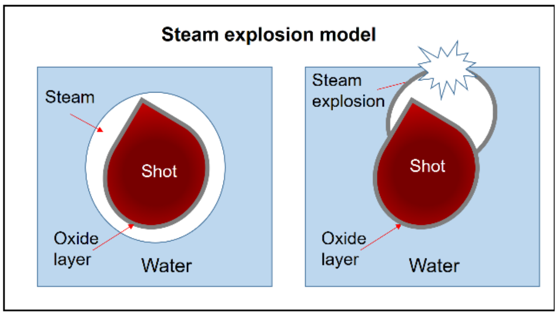


Fig 8. Steam explosion. Source: Author's design.

In each granule formed inside the water, an oxidation layer is formed, and then a coat of steam is progressively increasing around the shot. If the steam is not removed from the shot, the coat begins to grow until it's get-out from the water as an explosion. This mechanism corresponds to the sum of all shots and the explosion is instantaneous and it increases if the purring of metal to the tank growths.
The theory of explosions generated by steam accumulation in the water tank has been investigated extensively by several researchers, such as Kjetil Hildal in his paper "*Steam Explosions During Granulation of Ferro Silicon*" [14] and LS Nellson,

PW Books, R. Bonazza and ML Corradini in their paper "Steam explosions of ferrosilicon drops released into water" [15]. Then we will analyze the theory exposed.

3.1.2. Explosion by hydrogen formation

During the granulation process, the liquid metal falls into the tank and decomposes the water tank according to the following reaction:

$$M_{\text{(liq 1600 °C)}} + H_2O = M_{(oxid)} + H_{2(gas)} \qquad (3)$$

$$H_{2(gas)} + O_{2(gas)} = H_2O_{(liq)} + \text{explosion} \qquad (4)$$

M = metal; Liq = liquid; $M_{(oxid)}$ = metal oxide

The energy contained in the liquid hot metal pouring in the tank, decomposes the water molecule (inside the tank) into hydrogen and oxygen. The free oxygen in the water reacts with the hot solid metal, oxidizing the metal surface (3). While hydrogen gas leavings into the atmosphere It's burned with oxygen from the air (4). However, if the amount of discharge liquid metal into the tank is very big, the hydrogen formed increases significantly and upon exiting the surface generates huge explosion as explained by P- Å Lundstrom [13].

On the other hand, the explosion caused by accumulation of hydrogen is due to the instantaneous combustion that occurs when the hydrogen reacts with the oxygen of the air, and its intensity increases with increasing rate of discharge of metal in the water tank. Figure 9 shows a schematic of the hydrogen explosion mechanism in the tank.

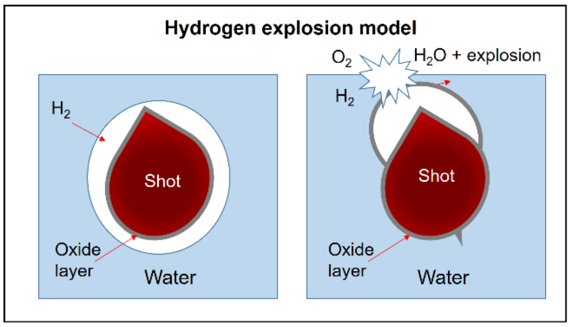


Fig 9. Hydrogen explosion. Source: Author's design.

During the process of granulation metals or alloys, there exist a risk of having several explosions in the tank. The risk is minimized by strongly stirring cooling water in the tank, in order to avoid the accumulation of water steam and hydrogen. The flow of cooling water, inlet and outlet must also be maintained throughout the all operation.

3.1.3. SAFETY ASPECTS DURING GRANULATION PROCESS

The granulation process is very effective and easy to handle. However, the level of security during the operation is very important to ensure the integrity of the workers and the equipment associated with the process. Within the main parameters that must be controlled during the granulation process we have:

The casting temperature of the metal or alloy previous granulation process, shall not exceed the calculated heat transfer design to maintain the water tank temperature below 75 °C. The percentage of the impurities in the metal or alloy must be controlled during the refining process to maintain the same flow and viscosity in the liquid metal during the pouring operation in the water tank. The rate of metal discharge for granulation must remain constant to maintain the thermal equilibrium in the tank. The exchange of hot water by fresh water must be kept constant during the granulation operation to prevent explosions. The quality of the basic equipment for the process must guarantee a safe and efficient operation during the granulation operation. The process must be safe for the operators, for the integrity of the basic equipment and with a friendly environment. Each company must have its own security policies, with good practices applied to the maintenance of basic equipment and a high level of training for operators associated with the granulation process.

4. CONCLUSIONES

The granulation of pure metals and alloys was successfully implemented since 1970 and was mainly incorporated by the ferroalloy industry as an alternative to facilitate the handling of raw materials in steel production, improving worker safety, the working environment and reducing operating costs.
The development of this technology and the implementation in several plants in the world has been led by UHT with good results since 1970. However, since the 1970's, UHT took the lead market and implanted more than 50 successful projects worldwide to produce metals and alloys in the form of shots. Table 1 shows the projects developed by UHT since 1970.

Table 1. Projects developed by UHT since 1970.

N°	Year	Alloy	Plant	Country	N°	Year	Alloy	Plant	Country	N°	Year	Alloy	Plant	Country
1	2015	JSW Toranagallu	SW Toranagallu	India	16	2005	Silver	Umicore	Belgium	31	1992	Steel	Electrostal	Russia
2	2014	Pig Iron	JSPL Angul	India	17	2004	MC FeCr	Samancor Ferr	South Africa	32	1989	Steel	Uddeholm	Sweden
3	2013	Pig Iron	Tata Steel KPO	India	18	2003	FeNi	Minera Loma d	Venezuela	33	1989	Steel	Uddamelt	Sweden
4	2013	FeCr	AFARAK Mogale Works	South Africa	19	2002	Pig Iron	Saldanha Steel	South Africa	34	1989	MC FeCr	Norsk Ferro As	Norway
5	2012	FeCr	FerroChromeFurnaces	South Africa	20	2001	SiMn	Tinfos	Norway	35	1988	Steel	Boschgottshardshütte	Germany
6	2011	Black Copper	Boliden Rönnskär	Sweden	21	2001	CrNi Alloys	ScanDust	Sweden	36	1986	Pig Iron	SSAB Luleå	Sweden
7	2008	FeNi	Xstrata Koniambo	New Caledonia	22	2000	Pig Iron	Voestalpine Do	Austria	37	1985	MC FeCr	Samncor, Ferrometals	South Africa
8	2008	FeNi	Skye Resources Fenix	Guatemala	23	2000	FeNi	Cerro Matoso	Colombia	38	1984	FeNi	Cerro Matoso	Colombia
9	2008	Pig Iron	ESSAR Steel	India	24	1999	Stainless Steel	Thos Begbie	South Africa	39	1981	FeSn	Capper Pass	UK
10	2008	FeNi	Barro Alto	Brazil	25	1998	FeNi	Cerro Matoso	Colombia	40	1979	FeCr	Middelburg Steel & Alloy	South Africa
11	2007	FeNi	Vale	Brazil	26	1997	Copper	Kennecott	USA	41	1978	FeSi	Elkem, Saltenverk	Norway
12	2007	FeNi	SNNC	South Korea	27	1996	Silver	Union Minière	Belgium	42	1978	FeMn	Elekem, Porsgrund	Norway
13	2006	Pig Iron	SSAB Oxelösund	Sweden	28	1995	Ni-matte	Outukumpu	Finland	43	1977	FeNi	SLN	New Caledonia
14	2006	Nickel Matte	BHP Billiton	Australia	29	1993	Si-metal	Peciney	France	44	1975	FeNi	SLN	France
15	2006	CrNi Alloys	B.U.S ScanDust	Sweden	30	1992	Basemetals	Outokumpu	Finland	45	1970	Pig iron	Uddeholm	Sweden

In addition to implementing the granulation process to manufacture ferroalloys as a raw material, it is currently being used to granulate pig iron on a large scale, either to keep it in stock or for sale to other mills.

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