Environment Protection Engineering

Vol. 25 1999 No. 3

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ECONOMIC AND ECOLOGICAL ASPECTS OF THE INTERNAL AND EXTERNAL RECYCLING OF USED FOUNDRY SANDS

In this report, a short overview of the economy and environmental impacts of recycling methods for used foundry sands is given. The application of foundry sands and different sorts of binder systems are described in the introduction. The state of usual foundry sand recycling, which is realised by a simple mechanical treatment, is represented. The need for avoidance and reduction of used foundry sands will be explained by the situation of German landfills. The established sand regeneration processes, which enable an improved internal recycling, are compared with respect to their economic requirements and their impacts on environment. Significant advantages and disadvantages of each of the three regeneration methods are discussed. The possibilities of utilising the used foundry sands as a substitute for fresh sands in the building industry are shortly described. Based on the shortcomings of the state-of-the-art of foundry sand recycling, some results of a case study, made for a Dresden non-ferrous metal foundry, are presented, giving several conditions and concrete costs for different disposal options as well as potential improvements.

1. INTRODUCTION

Foundry sands are used to form moulds and cores both in iron casting processes and non-ferrous casting processes. There exist several ways of producing the moulds and cores in the foundries. Moulds and cores formation depends heavily on one fact – whether they are hardened thermally or in a cold-hardening process. They have to be resistant to the casting forces and get lost after cooling down the cast iron piece. This kind of process is called *investment casting*.

Both organic and inorganic binders are used in the cold-hardening processes. Organic binders are chemical binders; the binding agents used in these processes are very often furane resins and amine resins. Furane resins are polymers of the furfuryl alcohol. Due to polymerisation the hardening of binding agents occurs, resulting in building up three-dimensional interlaced molecules which fix the sand particles to-

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gether. The polymerisation process is catalysed mostly by phosphoric acid and toluenesulfonic acid. The hardening starts at room temperature but warm-hardening processes are also applied.

Inorganic binders are physical binders consisting of clay or bentonite. A chemical inorganic process is the water–glass–CO_2 process.

Table 1

Application of chemically bound foundry sands in Germany in 1993

Method of making sand mould (treatment of foundry sand with...)	Mass of chemically bound sand being treated (in metric tons)	Share of mass (in percent)
Cold-setting resin	1.667.000	63
furan resin method	1.500.000	56
phenolic resin method	170.000	7
Polyurethane resin cold box method	500.000	19
Hot box and warm box method	178.000	7
Croning method	142.000	5
Water glass–CO_2 method	63.000	2
Alkaline resol resin method	60.000	2
resol–ester method	31.000	1
methyl formate method	29.000	1
Sulfur dioxide method	33.000	1
Resol–CO_2 method	9.000	0.3
Other methods (e.g. acetal method, thermal shock method)	< 8.000	< 0.3
Total sum	rd. 2.660.000	100

There are several kinds of sands used; mostly silica sands. Slurs are also added to improve the surface properties allowing more efficient casting. Table 1 gives an overview of the organic forming materials in casting processes used in Germany.

2. STATE-OF-THE-ART OF FOUNDRY SAND RECYCLING

The internal reuse of sand within a foundry is the state-of-the-art technology in Germany. After cooling down of the castings the moulds and cores break and are crushed to reuse the sand. Moulds are commonly made out of circulated sand, while cores are formed out of new sand due to quality reasons. Therefore the part of the sand in this cycle, which is equal to the part steadily added during the process, has to be separated. The quantity of sand equal to the new core sand steadily added to the sand cycle has to be separated from the cycle to keep the sand quantity within the cycle constant. In general, the sand is separated according to the size of its particles. Coarse grains are recycled, while fine grains which contain binders are separated. The separated fraction is called the *spent foundry sands* (SFS). Table 2 presents the foundry wastes in Germany in 1994, indicating SFS to be the largest fraction. Table 3 shows the number of different regeneration plants in Germany in 1993.

Table 2

Quantities of used foundry sands (Germany, 1994)

Kind of used foundry sand	Mass (in metric tons)
Bentonite bound sand	1.350.000
Cold-setting resin sand	170.000
Other foundry sands (sum)	28.000
Core sands with thermal stress	140.000
Core sands without thermal stress	49.000
Sands from surface finishing and blasting	104.000
Total sum of used foundry sands	1.841.000

Table 3

Occurrence of foundry sand regeneration plants in Germany, 1993

Type of plant	Number
Mechanical (including pneumatic) plants for regeneration of:	
– chemically (organically) bound foundry sands	> 200
– mixed sands from organically and bentonite bound foundry sands	5–10
Thermal plants for regeneration of organically bound foundry sands	~10
Multi-stage thermal and mechanical plants for regeneration of mixed sands from organically and bentonite bound foundry sands	3

Table 4

Calculation of profit of internal regeneration processes

No.	Formula	Profits
(1)	investment/running time	annual depreciation
(2)	interest rate × investment/2	annual interests
(3)	maintenance rate (chemical plants: 3–7% of investment [2])	annual maintenance
(4)	sum (1)–(3)	annual investment cost
(5)		operational costs
(6)		new sand costs including transportation costs saved
(7)		waste disposal costs including transportation costs saved

Table 5

Possibilities for handling used foundry sands

Used foundry sand			
Avoidance by internal recycling through:		**Utilisation** by external recycling	**Disposal**
1. Simple mechanical pre-treatment	**2. Sand cleaning (regeneration)** **Mechanical regeneration** / **Thermal regeneration**	**Utilisation of used foundry sands as substitute for mineral raw materials in construction industry**	**Disposal of foundry sands by** – Landfilling – Filling of mines
Objectives: – Re-granulating – Separation of very coarse and very fine material – Separation of metal parts	**Objectives:** – As in mechanical pre-treatment – Removal of binding mediums and other troublesome agents	e.g. – Asphalt production – Cement production – Brick production	
Result: Closed cycle for moulding sand	**Result:** Regenerated sand as substitute for fresh sand as: – Moderately regenerated sand for adding to moulding sand, improved cycle of moulding sand – Intensively regenerated sand for core sand preparation facilitates introduction of a core sand cycle		

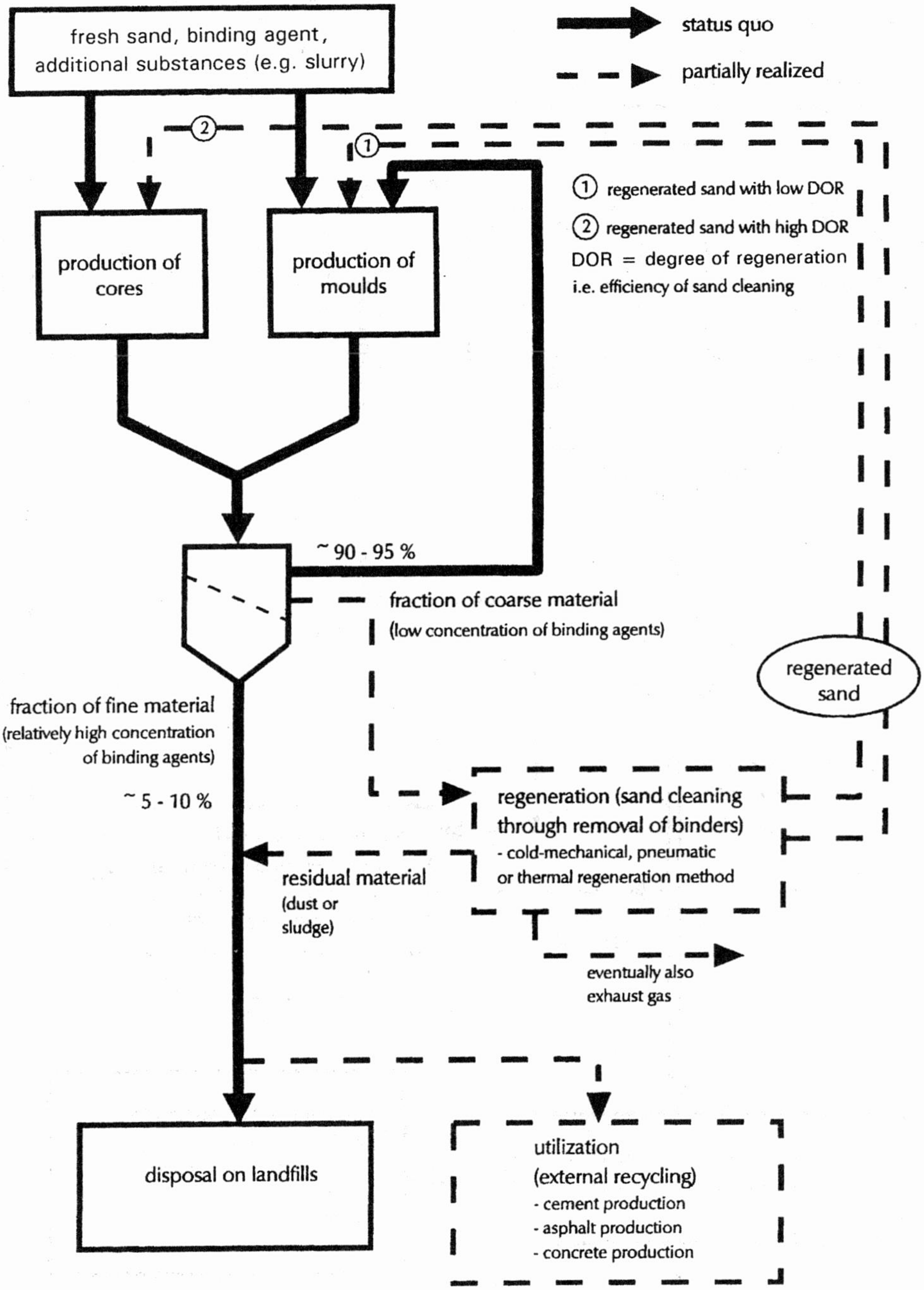

Fig. 1. Scheme of present foundry sand recycling

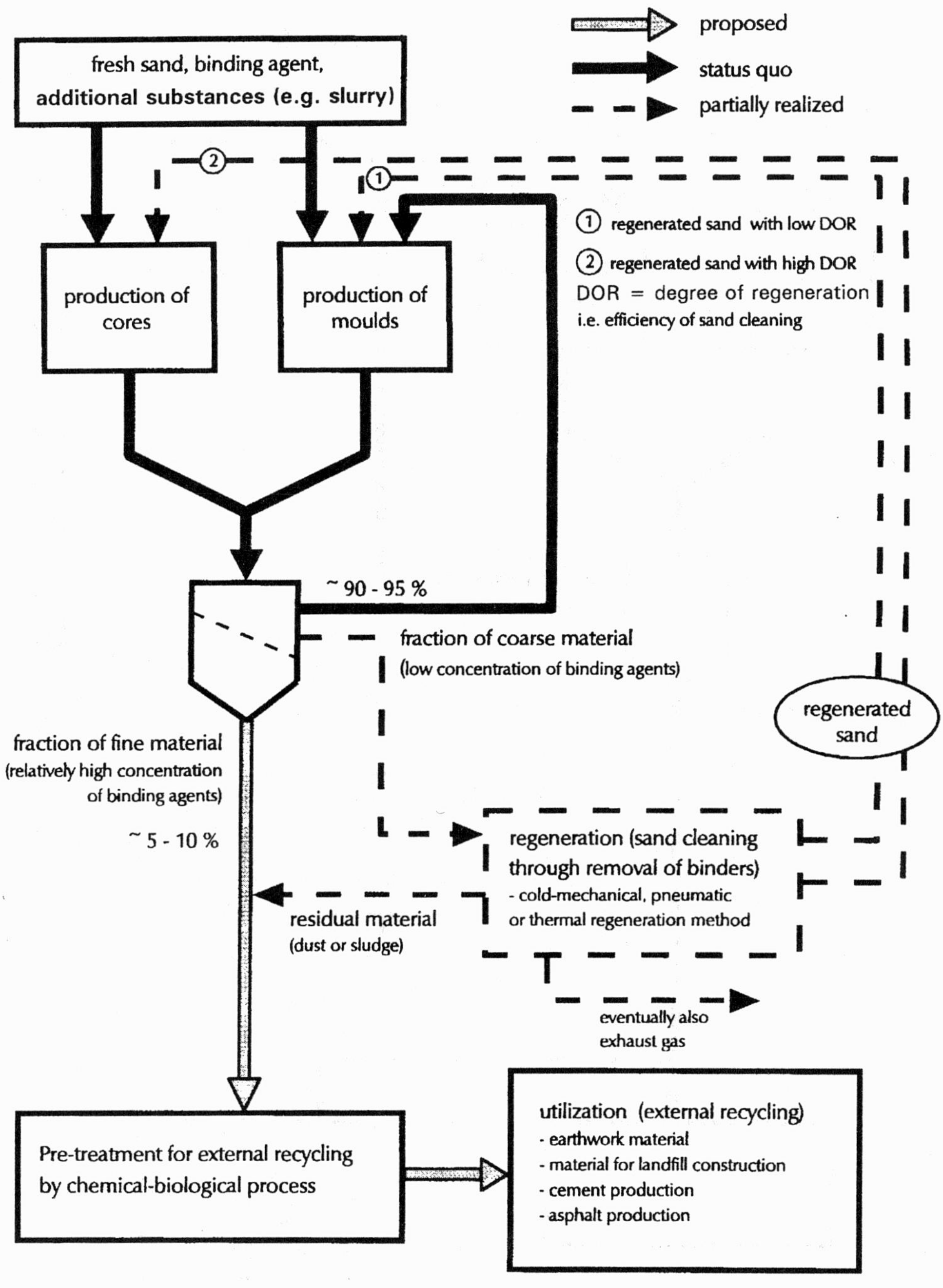

Fig. 2. Scheme of improved foundry sand recycling with proposed chemical-biological process

If nothing else can be done, these SFS have to be dumped. In order to avoid the need for deposition, we can choose one of the methods for *internal* and *external recycling* as shown below (see figures 1 and 2, table 4). There are two reasons to take account of the methods which allow us to avoid the deposition of SFS. The first is of economic nature: the costs of waste disposal are rising in a long term in Germany. The second deals with ecology: SFS are mainly a mass problem. Dumps in Germany can be built only on certain sites with appropriate geological properties. Due to ecological needs they are technical plants, containing, for example, basis lining and surface covers (the technical standard is given by legislation, whereas different disposal categories are distinguished depending on the kind of waste disposed of). Therefore it is reasonable to keep the free space on the dumps for future needs.

Due to these reasons, it is necessary to think about new technologies of internal and external recycling and to evaluate the existing methods in order to increase the extent of recycling.

3. INTERNAL RECYCLING

Internal recycling means the re-use of core and moulding sands after their processing and cleaning. Such a recycling differs from the simple sieving and crushing of remaining sand agglomerates after the casting process, which is already practised (see figure 1). The status quo in figure 1 gives in a simplified picture the state-of-the-art of the sand cycle in most of the foundries applying only crushing of agglomerates and sieving. This enables the sand to cycle 10–15 times on average (the sand circulates from 10 up to 15 times before leaving the foundry).

The *internal recycling* (indicated as "partially realised" in figure 1) means that the used sand has not only to be sieved, but the fine grain containing bonded binder has to be disintegrated. The used binders have to be taken away because their capability of fixing is irreversible.

The results of regeneration are as follows:

- Intensively regenerated sand, which can be used to replace new sand in the core and mould forming process. Regenerated sand and new sand are mixed, sometimes even 100% of regenerated fine sand is used for cores and moulds.
- Moderately regenerated sand that can replace only a part of the new sand.

The quality of regeneration is given by the *degree of regeneration (DOR)*:

$$\text{degree of regeneration} = \frac{\text{mass of removed troubling agents}}{\text{mass of troubling agents before regeneration}}$$

The degree of regeneration of fine regenerated sand ranges from 60 to 100%, while that of coarse regenerated sand from 20 to 60%. Production of fine regenerated sand enables the design of core sand circles but these are still not very common in German foundries.

Internal recycling means real avoidance of waste because it leads to a reduction of the dumped waste masses. A second advantage is a smaller amount of new sand needed. Thus, natural resources can be saved, especially those of quartz sands, which are needed mostly and are rather expensive.

Anyway, pollution can be reduced but not avoided completely. Depending on the kind of the process applied, pollutants are concentrated (mechanical treatment) or shifted to another medium (thermal treatment), see figure 4.

Processes allowing internal recycling can be itemized as follows:

- Cold mechanical processes.
- Thermal regeneration processes.
- Mechanical-pneumatic regeneration processes.
- Processes combining these methods.

The processes mentioned above represent the state-of-the-art technology [3]–[5].

4. ECONOMIC AND ECOLOGICAL ASPECTS

4.1. GENERAL ECONOMIC ASPECTS

Processing devices for internal recycling require investment and running costs that have to be compared with the running costs saved for disposal and new sands. The investment and running costs depend largely on the process used. The simplified calculation is given in table 3 [1].

Another method used to evaluate the economic success is to calculate the return of investment (ROI), giving the "time, the spent money takes to return". In joint-stock companies the method of calculating the payment of interest of the company capital is very often applied. In this calculation the money representing the relation between the company capital and bank capital of the company is spent for the investment. The result of this calculation is the payment of interest in an isolated view for this investment. This approach is used because joint-stock companies are responsible for a dividend payment.

It is noteworthy that planning costs of processing plants can represent about 8–25% of the total investment (under German conditions) [2].

4.2. COLD-MECHANICAL AND MECHANICAL-PNEUMATIC PROCESSES

Cold mechanical processes are the most efficient compared to other foundry sand recycling processes. They are characterised by low investment costs and low running costs, too. Therefore in Germany there is a trend towards these processes, as is shown in table 3. These processes can be started at low investments. Usually only one electric drive is needed and one vacuum device. The electricity costs are low. Furthermore, these processes can be utilised also as batch processes. Therefore, this is a technique to be implemented in small- and medium-size foundries as an own device.

In mechanical-pneumatical processes the investment costs are generally a bit higher, considering equal capacities. The electricity consumption is higher because of the need to produce compressed air. Due to the pneumatic conveyor principle batch processing is not very useful; the plants have to be run over several hours. Often the start and stoppage of these processes are not useful.

From the ecological point of view, the consumption of energy during these processes is lower than that necessary for thermal treatment. No fossil fuel is needed, therefore there are no waste gas emissions in the foundry. In contrast to thermal treatment, dusts containing bentonite can be separated and recycled, which is not possible during thermal treatment.

However, these processes cause one serious problem – the dust formation. This dust has to be disposed of, but some of its parts can be recycled. Bentonite-bound used foundry sands contain active bentonite and graphite, which can be recycled. Dusts from organically bound foundry sands contain large amounts of organic material which can easily be burnt. Because this material is considered as hazardous waste, the price of its disposal is rather high in Germany. The degree of its regeneration is a bit smaller than in thermal treatment and the abrasion of the sand particles is higher. Thus, the sands can only be recycled to smaller extent compared to the thermal treatment process. Because of the advantages of the mechanical processes this is not important.

4.3. THERMAL PROCESSES

Thermal processing means the incineration of such troublesome agents as binders. In comparison to mechanical processing they require higher investment and operation costs, including costs of the exhaust gas cleaning which is expensive. Furthermore a gas heating is necessary.

Batch processing is rather uneconomic because in the plants where these processes take place we need a long time to reach the combustion temperature and after combustion a long time to get rid of unused warmth. Therefore it is advantageous to build one big plant for several foundries instead of many small combustion plants.

The advantages are as follows: smaller amounts of dust in the recycling process; smaller degree of abrasion of the sand particles resulting in better cycling of the sand and lower consumption of fresh sand. The degree of regeneration approaches 100%, therefore core-sand cycles are possible, and thermally-regenerated sands possess a fresh sand quality.

Taking into account the degree of regeneration, one remark must be made: certain sands do not require a degree of regeneration of 100%. After mechanical regeneration of at least 40%, polyurethane (PUR)-Coldbox-sands, for example, have a better quality (expressed in bending strength) than fresh sands.

4.4. EXTERNAL RECYCLING

External recycling means the processing which allows us to reduce the amount of waste sands that should be disposed of. In small- and medium-size foundries, external recycling is an interesting alternative to the capital-intensive internal recycling. Principally foundry sands can be used in each kind of production where sands are necessary. In the past, the following fields were investigated:

earth and road construction,
landfill construction,
cement production,
brick production,
concrete industry,
chalk-sandstone production,
asphalt production,
filling material in closed coal-mines.

The costs have to compete with the disposal costs, transportation included. Taking into account the environmental impact, the toxic agents of the waste sands have to be considered (heavy metals, phenols, polycyclic aromatic hydrocarbons). According to German legislation cancerogenic emissions must be minimised.

5. CASE STUDY IN A DRESDEN FOUNDRY

The cold hardening is advantageous during production process because of the saved time and equipment (no hardening furnace is needed, for example). Due to this reason, especially in small- and medium-size non-ferrous casting foundries, the cold hardening becomes more important.

Despite the above economic advantages the foundry production is associated with some disadvantages, especially from ecological viewpoint. Due to German legislation hazardous wastes have to be dumped on dump site (LAGA-Class 2 [6]). They may be partly used in cement works, asphalt industry or as an admixture of concrete, but in this case they have to be processed first in order to separate the binders from the sand. Only the sand can be reused.

The costs of disposal are not definitely fixed but they approach 100 DM/t. The same price has to be paid for a new sand material. The sand is recycled in the foundry process 10–15 times, as shown in figure 1.

Some larger foundries use an additional processing step to separate the binders from the sand (mechanical or thermal treatment). Thus, the sand cycle number can be increased (see figure 1). Because the costs of the hazardous waste disposal are rising in Germany in long term and the costs of thermal treatment of sand to be reused are near 500 DM/t, we have started our investigations in co-operation with the Dresdener Formguß GmbH, a non-iron casting foundry. The aim was to find out a cheaper way to treat the used sand, which makes it possible to reuse the sand in construction industry as filling material or concrete additive (see figure 2).

According to the prices mentioned, the processing costs had to be lower than 100 DM/t. Due to the molecular structure of the binder it seems possible to apply a combined chemical-biological process [7]. This investigation proves that there is now a market for these sands, e.g. in the cement and asphalt industry such sands are already used. However, the costs have to be lower than 100 DM/t. These funds can be implemented in Germany because of the existing legislation allowing us to burn 25% of waste during industrial processes in power plants (25% means 25% of the energy content).

Mechanical treatment applied to internal recycling shown in figure 1 can be used for the treatment in external recycling presented in figure 2. If the cement or asphalt industry is not capable of treating wastes, which can depend on the existing air cleaning equipment, it is worthwhile to check the technical feasibility of the chemical-biological approach.

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EKONOMICZNE I EKOLOGICZNE ASPEKTY WEWNĘTRZNEGO I ZEWNĘTRZNEGO RECYKLINGU ZUŻYTYCH MAS FORMIERSKICH

Omówiono opłacalność metod recyklingu zużytych piaskowych mas formierskich i ich wpływ na środowisko. Wymieniono możliwe zastosowania mas formierskich wraz z różnego typu systemami wiążącymi (spoiwami). Przedstawiono powszechną metodę recyklingu zużytych piasków formierskich z wykorzystaniem prostego oczyszczania mechanicznego. Potrzebę zmniejszenia ilości zużytych mas formierskich wyjaśniono, opisując stan składowisk odpadów w Niemczech. Zanalizowano powszechnie stosowane procesy regeneracji piaskowych mas formierskich, umożliwiające efektywny wewnętrzny recykling, a także ich opłacalność i wpływ na środowisko. Omówiono podstawowe zalety i wady trzech metod regeneracyjnych. Zanalizowano możliwość wykorzystania odzyskanego piasku formierskiego w budownictwie (zamiast świeżego piasku). Na podstawie przeglądu metod recyklingu piaskowych mas formierskich zanalizowano gospodarkę zużytymi masami formierskimi w odlewni metali nieżelaznych w Dreźnie. Zanalizowano koszty różnych wariantów utylizacji mas formierskich i wytyczne do usprawnienia istniejącej technologii.