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Opinion

Circular Economy and Foundry Sands: Opportunities and Open Issues

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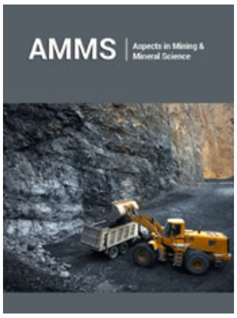

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Opinion

In the past, the disposal of Waste Foundry Sand (WFS) was mostly dependent on landfilling, but the shortage of landfills and rising landfilling costs resulted in an increase in production costs, and environmentally, there was a negative aspect of the disposal of useful resources. In addition, the relevant investment costs, the lack of consumer interest in products produced using recycled aggregates, as well as insufficient nurturing measures and deficient regulations contributed to limiting recycling the WFS. Today, interest in the recovery of foundry waste, including foundry sands, is increasing and investors are looking for novel ways to exploit this resource. The main drivers of the changes are a more and more restricting legislative environmental policy and the need of increasing the efficiency of the production processes. Indeed, the direct environmental impact (waste, emissions, and discharges) and indirect (consumption of raw materials from quarries and mines) will have much higher costs in the next future. This situation represents an opportunity to restructure production processes differently and to obtain an optimization of the natural resources never achieved before. The upgrading of production processes can be an opportunity for a general reorganisation of the foundry sector and the development of new industrial symbiosis. Sand, gravel, and crushed stone play a significant role in the global economy, with concrete being a central pillar of urban development [1]. Sand and gravel are the second most exploited natural resource in the world after water, with 50 billion tonnes extracted every year [2]. Several developing countries, due to exponential urban development, have also led to greater environmental concerns: the extraction of sand, which often occurs near rivers, has led to pollution, and the risk of flooding and erosion. Thus, the extraction of sand is associated with health and safety risks.

Sands are composed of mineral matter with a diameter that varies approximately from 2 to 0.05mm. This definition does not consider the chemical nature of the grains. The sands most used in foundries can be relatively high-value raw materials, primarily composed of silica (SiO_2). In some cases, there are small amounts of feldspars (aluminium silicates and alkaline or alkaline earth oxides), mica and other common minerals. On the market, there are also sands with superior characteristics given by some minerals, including zircon ($ZrSiO_4$), chromite ($FeCr_2O_4$), and olive oil [$(MgFe)_2SiO_4$]. The deposits of natural sediments result from geological sedimentation processes and the origin of the material is due to atmospheric erosion. The quality of the sands depends on their composition and is closely related to the site from which they originated. Therefore, foundry sands are siliceous sands at different degrees of purity and cost, used for moulds and cores of castings of ferrous (Fe and steel) and non-ferrous metals (such as Cu, Al, and brass) [3]. Sand casting consists of pouring the molten metal into a sand form, letting the metal solidify, breaking the shape, and removing the rough. The quality of the result is determined by the process and the used sand. With this process, it is possible to realize a single object or millions, but each time the form is destroyed and a new one must be created. The silica sand thermal expansion generates mould movement during casting and cooling. Sands containing feldspars have a smaller thermal expansion and sintering point than pure quartz and are widely used to minimize dilation defects in castings. Particle size distribution is also relevant since small sand grains have a large surface area and require more binder. Thus, a coarse fraction of the sand is used, which still guarantees a good surface finish. Compared to silica sand, chromite sand is more refractory, is thermally more stable and has greater cooling power. Moreover, chrome sand provides a better surface finish on large castings. The general characteristics of zircon sand are like those of chromite, and it is used for the moulding and making of cores with complex geometry. Olivine sands contain minerals such as forsterite and fayalite are usually used for stamping and producing cores in the casting of manganese steel. One of the main additives used in moulding is bentonite, a clay with a lamellar structure. By water, the clay swells and can be used to coat the grains of sand. Natural sodium bentonites swell considerably when mixed with water and are commonly used in the United States. In Europe, calcium bentonites treated with sodium carbonate are more diffuse because of their lower cost.

In recent decades many chemical binders have been developed. Coal dust is also usually added to green sand for casting iron. In addition to the black and sticky powder caused by handling, coal dust may contain or generate Polycyclic Aromatic Hydrocarbons (PAHs) during casting. There are various types of coal dust or coal dust substitutes. The castings manufactured in foundries are predominantly made in so-called green sand molds, with green sand being quartz sand with inorganic binders such as bentonite [4]. The green sand is mechanically solidified with the addition of water by shaking to the required dimensional stability. To form the inner contours of the casting, core pieces are inserted into the green sand molds, which are formed from quartz sand with the addition of organic binders, such as furan resins or phenolic resins. The core gets its strength through the chemical hardening of the binders. After the casting has solidified, it is separated from the mold. As a rule, the core pieces disintegrate due to the thermal load during the casting process, resulting in a mixture of green sand and core sand, which must be processed if it is to be used again. To treat green sand obtained after the casting process, it can be thrown against an impact bell at high-speed using an air stream, with bentonite being blasted off from the quartz grains. With thermal processes, core sands with organic binders are treated so that all organic constituents of the binders are burned, and the quartz sand can be reused. However, the reuse of regenerated old sands is essentially limited to the production of molds. For core production, new sand must be used predominantly to ensure the required core strength with given amounts of the binder. The processing of sand mixtures of cores and green sand can be extremely problematic since it cannot generally be regenerated satisfactorily and very often is disposed of in landfills. Because of the great variability in the composition of foundry sand wastes (WFS) and the presence of contaminants, their recovery, regeneration, and recycling are always challenging. The uses of WFS as-it-is in road sub-base or agriculture have been proposed, but it can be problematic since the untreated waste may release contaminants and affects the environment, and, in particular, groundwaters [5]. Treated WFS are widely used in civil engineering and building materials [6,7]. Indeed, several projects have been proposed to ensure the recycling of WFS (for example in Europe, the LIFE projects Ecotyle and FoundryTyle) but their achievements, even if encouraging, could not be exploited to the global sector because of the great differences in the composition and contaminants of materials and processes.

During the years 2020-2022, the Italian Association of Foundries named ASSOFOND promotes the analysis of foundry sands and furnace slags in a frame of a research project financed by the CARIPLO Foundation. During the project, which involved IUSS Pavia, the University of Brescia and the Consortium INSTM, foundry sands from 38 foundries located in the Lombardy Region were analysed and compared. The conclusion was that WFS are extremely heterogenous, and it is unfeasible to have a single general protocol for their recycling. Indeed, the substitution of raw materials with WFS when the composition or the presence of specific contaminants are critical, as in ceramic or glass sectors, strongly depend on the origin of the sand and the additives used in the foundry process. Indeed, always to recycle the WFS two primary action are needed:

A. their careful selection and characterization.

B. the definition of raw material physical and chemical characteristics and tolerances mandatory in the specific recovery process.

Besides, the research and the policy must create a favourable environment for the development of new markets for WFS in the civil sectors (cement, premixed cementitious mortars, bituminous conglomerates) and look for new sustainable industrial symbiosis. This can be achieved by the definition and validation of shared BATs and standards to get suitable by-products, defining the best treatments, and supporting the necessary investments. A relevant achievement can also be the implementation of platforms that will discipline the waste exchange to grant consistency in the quantities supplied and guarantee the quality of the materials. In this frame, a great market opportunity can be in the ceramic and glass sectors, which are expected to strongly grow in the next years. However, even if some studies showed the potential use of WFS in the ceramic [8] and glass sectors [9], the industrial feasibility of the proposed process must be demonstrated.

In conclusion, the production sectors must be adapting to the new paradigm of ecological transition, mitigating their side effects on the quality of the environment and foundries are among the major. Indeed, the exhausted foundry sand has great potential, however, many factors contribute to the low level of its reuse:

a. the lack of normative that ensures environmental protection and encourages appropriate beneficial reuse can be very challenging,

b. the lack of an established process for evaluating and permitting reuses.

c. Prospective stakeholders may not be aware of the potential uses of WFS or assume that WFS may not perform properly from an engineering standpoint, or that it may contain unacceptable concentrations of toxic constituents even after treatments.

d. foundries may not be aware of the potential of the sand or may not have considered simple operational changes that could have dramatic effects on the characteristics of WFS and thus enhance their ability to find alternatives to landfill disposal.

To overcome these barriers, a strong collaboration between research and industry is compulsory, to generate the essential network of skills and achieve as soon as possible the industrialisation of successful laboratory-scale projects and the establishment of solid supply chains for the materials.

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