The Journal of The Institute of Cast Metals Engineers

FOUNDRY TRADE JOURNAL INTERNATIONAL

DIECASTING WORLD

Volume 193 No. 3763 April 2019

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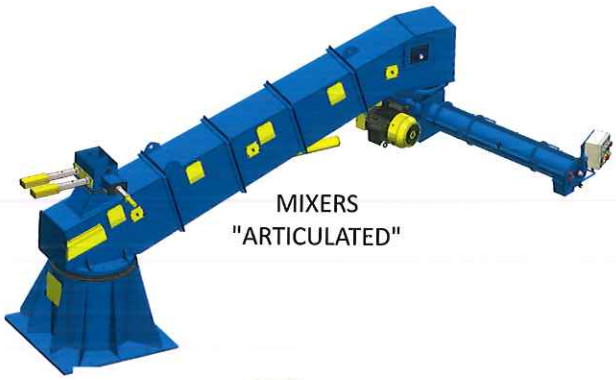

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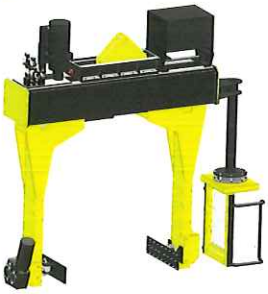

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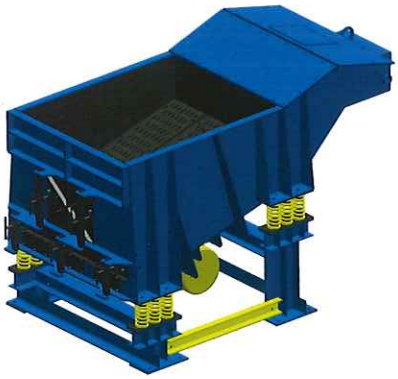

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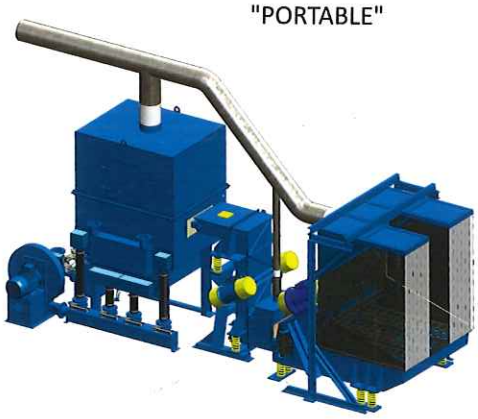

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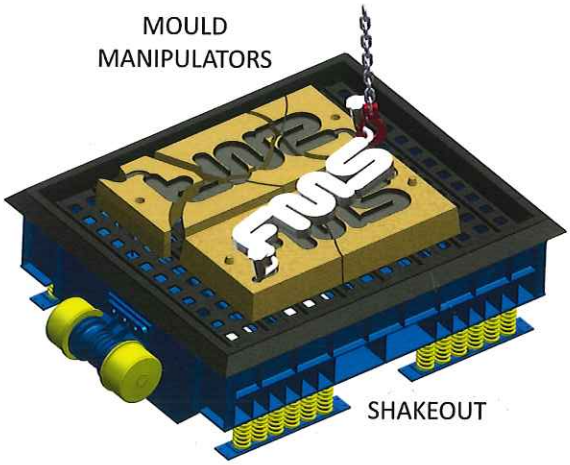

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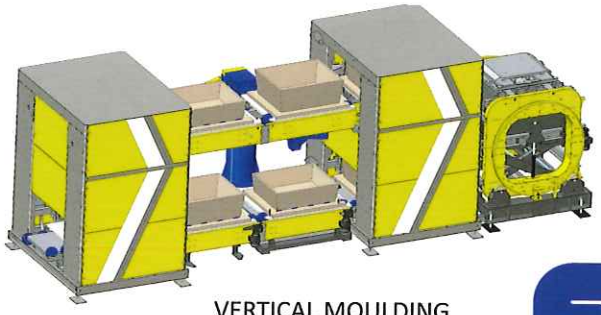

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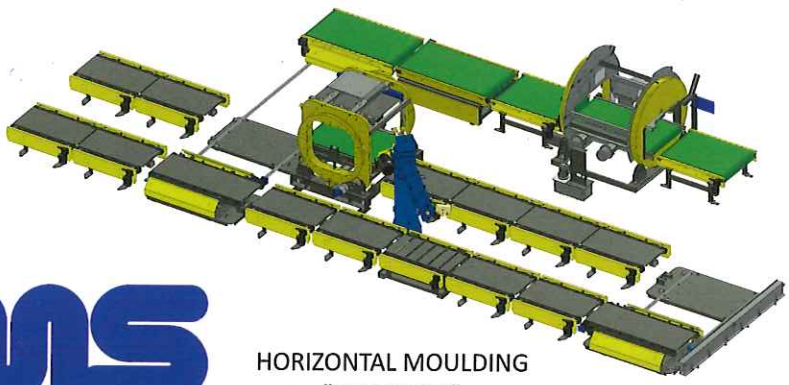

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CONTENTS

Volume 193 No. 3763 April 2019

REGULARS

FEATURES

TECHNICAL PAPER

Lynn Postle, FICME

From the editor

Whilst the foundry sector has taken large leaps in relation to health and safety, it is now recognised that more still needs to happen to support employees in terms of their mental health and wellbeing. The industry is keen to make working conditions as comfortable as possible to retain existing and attract future employees into a dynamic and exciting industry.

This month we highlight some of the initiatives to assist companies in their quest to meet H&S legislation and improve conditions for all of those either working on or visiting the site. It is encouraging to note that the impacts of working in a global business environment – 24/7 availability, data capture, deadline pressures etc. – are being acknowledged by companies in our sector and steps are underway to nurture a greater work/life balance. Taking care of our people is a top priority, after all if our people prosper so does our business and our wider industrial sector. There are of course, some stark warnings that need to be heeded, but by accepting improvements can always be made we can further develop our companies.

This is also the case in terms of the old adage of "not resting on your laurels". In this issue we also look at some of the investments being made throughout industry in terms of site expansions and people development. For many, an ongoing increase in demand and a trend towards larger equipment has forced the need to physically grow the business, in all cases there is a desire to future-proof the business to accommodate future customer requirements.

It is an exciting time for our industry as the world continues to recognise the capabilities and value of cast components, thus both our metal casting and supply companies are responding with continued technological improvements and tight delivery schedules. Long may it continue.

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- Automated processes and connectivity
- Diecasting

Don't miss the May 2019 issue

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Rivers Media Services
Tel: +44 (0) 1432 275 566
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Journal Subscription Rates
UK £215.00; USA $430.00; EU €305.00; RoW £299.00. Single copies £26.00 (post free). Includes one copy of *Foundry Yearbook and Castings Buyers' Directory*.
Tel: +44 (0) 1544 340332
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FOUNDRY TRADE JOURNAL is the official publication of The Institute of Cast Metals Engineers. It is also the official organ of The Pattern, Model and Mould Manufacturers Association and The Foundry Equipment & Supplies Association. The Institute of Cast Metals Engineers is a registered charity. ISSN: 1758-9789

Spent foundry sand valorisation in construction sector through the validation of high-performance applications

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ABSTRACT

Disposal of spent foundry sand (SFS) is one of the most pressing environmental concerns the metal casting industry faces nowadays. Despite its high silica content, that waste is typically landfilled, thus losing a valuable non-renewable material. The construction sector seems a promising alternative to beneficially reuse spent foundry sand, provided that concentrations of residual organic compounds from binders and metals from casting are below certain limits.

This paper describes the activities performed in the project LIFE ECO-SANDFILL, concerning the determination of environmental and technical properties critical for the development of SFS in construction applications. A novel mechanical SFS reclamation system has been built and integrated in a Spanish foundry, to make reclaimed sand reach the required quality for several applications. The first experimental results are discussed.

INTRODUCTION

Spent foundry sand (SFS) generation is intrinsic to sand casting of metals. The amount of waste sand generated annually at European level can be estimated in the range of 4.5-9mt/yr[1], mostly coming from around 1,900 ferrous foundries active in Europe[2]. Less than 35% of this waste is recovered in a few applications, mainly in the cement industry, the remaining part is landfilled.

SFS from ferrous casting is typically a non-hazardous granular material (classified under codes 100906/08 in the *List of Waste* [3]), uniformly distributed in two to three sieves, with 80-95% of the particles between 0.125-0.5mm, subangular to spherical shape and high silica content (80-95%). Those characteristics make SFS a likely candidate to become a source of recycled silica sand to be used as a secondary raw material in several end uses.

Sand and gravel, typically used in civil engineering or road construction, represent one of the major solid materials extracted worldwide. Significant environmental impacts are associated with its extraction, processing and transportation. Hence, the use of SFS as secondary fine aggregates in the construction sector seems to offer promising development options to divert valuable sand waste from landfill, while avoiding the mining and dredging of new sand.

The EU-funded LIFE ECO-SANDFILL project is investigating the use of SFS as fine aggregates in construction, specifically for geotechnical applications (embankments), flowable mortars and controlled low strength material (CLSM). The potential for high-quality reuse in foundry moulding shops is also being evaluated.

ASSESSMENT OF ENVIRONMENTAL CONDITIONS FOR DEVELOPMENT OF FOUNDRY SAND IN CONSTRUCTION

Depending on the way the sand is incorporated into the construction applications, it can be broadly classified into two main groups: (1) *bound applications*, where the aggregates are encapsulated in a cementitious matrix to form a final product (concrete, mortars, asphalt, etc.) and (2) *unbound or geotechnical applications*, where the sand is compacted but not encapsulated, being directly in contact with soil (embankments, pipe bedding and road base materials, etc.).

To use the foundry sand safely as raw material in construction, it must meet relevant technical specifications and, additionally, fulfil several environmental conditions, especially in the case of unbound uses. Currently, SFS use in the construction sector is not specifically addressed in any regulation at European or local level. For this reason, regulations existing for development of other waste streams have been used as a reference – the quality criteria selected in LIFE ECO-SANDFILL pilot experiences stem from the construction and demolition waste legislation in the Basque Country (Spain)[4], which stipulates that recycled aggregates intended for unbound applications must fulfil leachate limit values for inert waste landfilling[5] and meet contaminant concentration limit values stated in soil pollution regulation[6], whereas no environmental conditions are given to hydraulically bound applications.

With the aim of identifying critical parameters in SFS (green and chemically bonded sand) for its valorisation, 20 samples generated in various Spanish ferrous foundries were analysed for environmental compliance, according to the aforementioned standards.

Contents of potential contaminants in sand composition proved to be below the regulated limits for soil pollution in all samples investigated. However, pollutant limits in leachate were exceeded in several samples. A total of 60% of the samples analysed fail to meet the leaching limits for fluoride and total dissolved solids (TDS) and 70% exceed the content limit for dissolved organic carbon (DOC). TDS values are not critical as long as the sulphate and chloride are below the limits, which is what usually happens. The measured values of other leachate parameters such as Zn content and phenol index have been

Component in leachate	Limit Value (mg/kg) Inert Waste
DOC	<500
Fluoride	<10
Total Dissolved Solids (TDS)	4000
Phenol Index	<1
Zinc	<4

Table 1 Critical environmental parameters of SFS (leachate) for use in construction unbound applications

found to be around the limits in a few samples. Furan bonded sands have shown the highest sulphate values.

Those experimental results suggest that only five, out of the more than 125 regulated chemical substances of environmental concern for unbound construction applications, may require close monitoring and correction measures in SFS (Table 1). The present work would demonstrate whether the application of sand reclamation technologies in the foundry can lead to further removal of impurities and foreign materials from used moulding sand and overcome those leaching issues.

SAND RECLAMATION TECHNOLOGY TO ENHANCE SFS DEVELOPMENT

The reclamation technique implemented in the project consists of scrubber style recovery with centrifugal force, in which the sand grains are rubbed together and against the walls in a closed system, removing effectively impurities from the surface of the silica sand. One of the advantages of this technology is its versatility, as it can be readjusted according to the characteristics of the input sand (composition and binder) and the specifications requested for its final application. Variables such as rotation speed of the attrition chamber, cycle time, air flow and pressure drop can be combined to achieve the specified quality in the output sand.

In the framework of the LIFE ECO-SANDFILL project, recovery options, before and after reclamation, of two SFS flows from steel foundry Fundiciones Del Estanda S A have been investigated: surplus greensand (GREEN SFS), which uses bentonite as binder, and chemically bonded sand of the phenolic-isocyanate type (CHEM SFS).

Samples of both types of sands have been subjected to reclamation adjustment trials in a pilot plant, in order to: (i) quantify the degree of impurity removal achieved; and (ii) select the best operation variables to run a reclamation prototype under industrial conditions, as to produce sand of the required quality for three designed construction demos.

1. Controlled low strength materials (CLSM) for backfilling applications typically consisting of a mixture of 1700/100/200-350kg/m³ of sand/cement/water, respectively; designed to backfill voids or trenches in urban repair works or underpasses for tracks in the railway network. Uniaxial compressive strength (UCS) of 1MPa is required.

2. Flowable filling mortar for non-structural applications, such as tunnel concrete coverings, filling in pumping well and decanting pool, or backfilling mortar in foundation slabs of embankments. The requested value of UCS for that application is 15MPa. Physical-chemical specifications for mortar aggregates are set out in UNE EN 13139 standard[7].

3. Embankment. Use of SFS as granular filling material for embankment construction without liners encapsulation, demonstrating technical performance (compaction properties, loading capacity, stability, etc.) and non-existence of environmental risks (leaching issues). The engineering requirements for granular filling material in embankment constructions are laid down in Spanish regulations on road and bridge works[8].

Fig.1 LIFE ECO-SANDFILL reclamation prototype installed at Estanda (left) and compared SEM images (100x magn.) of chemically bonded SFS before (right, top) and after treatment in the system (right, bottom)

About 20 combinations of reclamation variables were tested in the adjustment trials and the obtained sand from each run was characterised for a set of parameters established as cut-off criteria considering technical requirements. Contents of organic matter, soluble salts and fines in SFS seem to be the most critical aspects, since they may influence the setting time and mechanical resistance of concrete and mortars, as well as the bearing capacity of embankments. Thus, the efficacy of the reclamation technology has been measured in terms of loss on ignition (LOI), particle size (AFA), % fines, % soluble chloride and sulphate.

In parallel, the environmental characterisation of samples of untreated and reclaimed GREEN and CHEM SFS and their eluates was performed, finding that only CHEM SFS reclaimed in the prototype fulfilled environmental conditions on the leachates, as well as on the sand composition, and was, consequently, the only sand grade eligible for development in bound and unbound construction applications.

Through the application of multicriteria analysis, the optimal operating conditions of the reclamation process has been ecodesigned by reconciliating best properties in the obtained sand and minimal environmental impact of the process. Under those hypotheses, the best operational conditions were set at: batch size = 60kg, rotational speed of the motor of the attrition chamber equal to 2,235rpm and residence time = 60s for CHEM SFS.

Those design guidelines have been considered to manufacture a custom-built prototype that has been integrated into the existing recovery circuit of the chemical sand at ESTANDA (fig.1) and to operate it to obtain the amounts of reclaimed sand necessary for the three construction demos.

VALIDATION OF RECLAIMED SFS AS FINE AGGREGATES IN CONSTRUCTION APPLICATIONS

Once established that, attending to environmental constraints, only reclaimed CHEM SFS could be used as secondary sand in unbound applications, it has been assessed as to whether it also complies with the corresponding full set of technical requirements.

Technical requirements for embankment: reclaimed CHEM SFS met the limit values (PG-3) for

Property	Limit Value (tolerable soil)	Reclaimed CHEM SFS	Reclaimed GREEN SFS
Organic Matter	<2%	0.66	0.87
Gypsum Content	<5%	0.31	0.34
Soluble Salts	<1%	0.06	0.95
CBR Value (Foundation & Core)	>3	5.1	30.51
Liquid Limit (if Plastic)	<65	Not plastic	Not plastic
Plasticity Index (if Plastic)	if LL>40 , PI>0,73*(LL-20)	Not plastic	Not plastic
Collapse	<1%	0,09	0.03
Swelling	<3%	1.9	0.25

Table 2 Characterisation of reclaimed foundry sand according to PG-3 Art.330

Non-structural mortar constituents	SFS dosage				
	0%	10%	20%	35%	50%
Cement 22.5R (kg/m³)	350	350	350	350	350
Water (kg/m³)	205	205	211	214	227
Natural Sand (kg/m³)	1491	1341.9	1193	969	680
Reclaimed CHEM SFS(kg/m³)	0	149.1	298	522	675
X-Seed Additive (%)	0	1	2	4	5
UCS 7 Days (MPa)	20.35	16.65	15.45	13.7	10.45
UCS 28 Days (MPa)	28.1	23.05	20.73	18.45	13.53
UCS 90/180/360 Days (MPa)	Not measured yet				

Screed mortar Constituents	0%	10%	20%
Cement 22.5R (%)	10	10	10
Water (%)	7,5	7,5	7,5
Natural Sand (%)	82,5	74,25	66
Reclaimed CHEM SFS(%)	0	8,25	16,5
X-Seed Additive (%)	0	1	2
Density EN_1015-6 (kg/m³)	2,00	2,04	2,09
UCS 7 Days (MPa)	7,26	8,05	10,28
UCS 28 Days (MPa)	10,09	11,18	14,28
UCS 56 Days (MPa)	11,32	12,07	13,95
UCS 84 Days (MPa)	13,25	12,57	14,33
UCS 365 Days (MPa)	Not measured yet		

Table 3 Dosages tested in laboratory for non-structural mortars and screed mortars and the comprehension strength of the mixtures

tolerable soil to be used in the core and foundation of embankments (CBR≥3). The modified proctor showed a dry density / optimum moisture content of 1.78t/m³ / 10.0%. However, SFS shows discontinuous grading and spherical shape that compromises the compactability and embankment stability. For this reason, it has been proposed to blend it with borrow material at a 80:20 ratio. To be noted that technical requirements for tolerable soil were also met by the GREEN SFS generated at ESTANDA (Table 2).

Technical requirements for mortar: measured values of properties of reclaimed CHEM sand are below threshold values specified in UNE-EN 13139 for mortar aggregates, except for fines content and volume stability (as water soluble substances), which is linked to the fact that particle gradation of SFS does not fit the typical grading curves of construction aggregates. Those results recommend designing carefully the SFS dosage in mortars for non-structural applications.

When defining SFS maximum substitution ratio achievable in bound applications (mortar and CLSM), different dosages of SFS (0%, 10%, 20%, 35%, 50%, 100%), have been studied and the performance (workability, durability, mechanical resistance, etc.) of the mixtures evaluated. The evolution of mechanical strength over time is monitored through measurements of uniaxial compression strength at different frequency during one year (Table 3).

UCS values over 2MPa were measured at 28 days for mixtures of CLSM with 100% substitution of natural sand with reclaimed CHEM SFS. It guarantees fulfilment of the target UCS >1 MPa set and, consequently, 100% substitution ratio would be used safely. Reclaimed CHEM SFS used in mortar mixtures with excessive natural sand substitution ratios >50% caused high cement consumption, growing water demand and a loss in mechanical properties. However, substitution ratios up to 35% can make a favourable effect on the mechanical properties since the fineness of SFS can cause a decrease in the

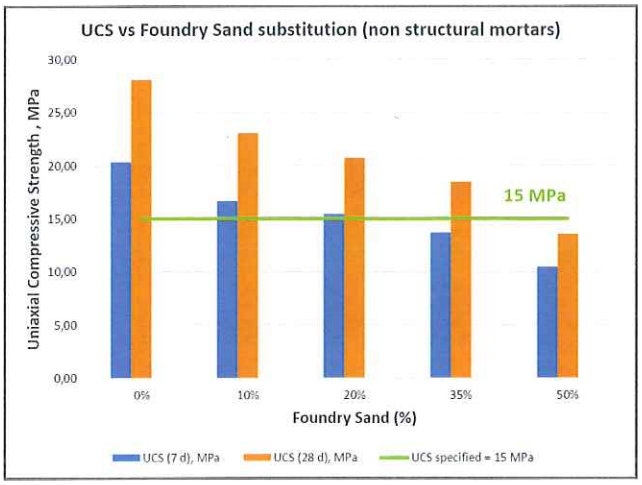

Fig.2a Compressive strength of non-structural mortars with different foundry sand substitution ratios

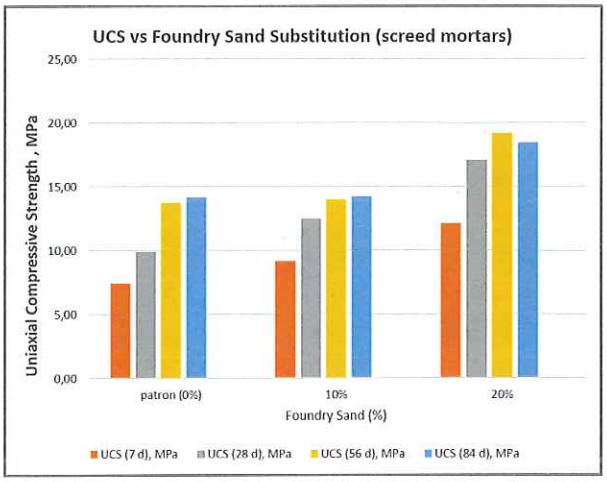

Fig.2b Compressive strength of screed mortars with foundry sand substitution in the 0.5-0.125mm size fractions ratios

porosity of the mortar and an increase in the density of the mixture (fig.2a).

Observed effects on increased flowability and water demand recommend particle-size distribution should be arranged carefully and that natural aggregates should be replaced, preferably in the size between 0.125-0.5mm (fig.2b).

CONCLUSION

SFS from ferrous foundries are typically non-hazardous waste that do not reach the inert waste classification due to their leaching behaviour, thus, its use in unbound construction applications should be controlled. In a study of SFS samples from various Spanish foundries, the most critical parameters are DOC, fluorides and TDS. In the LIFE ECO-SANDFILL project it has been demonstrated that, by subjecting to a mechanical reclamation treatment, the phenolic-isocyanate waste sand of a steel foundry reached the environmental acceptance criteria required in different construction applications.

Regarding the physical characteristics of the foundry sand – particle gradation, grain fineness number (AFA) and grain shape are important determinants of flowability, compacted density and strength of SFS mixtures. Fineness relates to higher water demand in mortar mixtures. Round grains provide superior flowability, but lower strength yield compared to angular grains. Sphericity and size homogeneity hinder compaction and bearing in embankment applications. Therefore, the SFS substitution ratio should be selected depending on the final application requirements:

- Reclaimed SFS complies with leachate limits for inert waste and specifications for tolerable soil in the core and foundation of embankments (PG-3, Art.330). Blending SFS with borrow material at 80:20 ratio would enhance compactability.
- In CLSM applications (trenches backfilling), where low compressive strength is required (1MPa), 100% substitution can be achieved.
- In flowable mortars (screed, non-structural elements), SFS dosages should be kept lower than 35% of total sand to meet the specified UCS at 28 days (15MPa). Evaluation of the long-term mechanical performance is necessary to ascertain durability. Substitution only in the 0.5-0.125mm size fractions of natural aggregate is recommended for minimum alteration of the aggregate gradation in mortar mixtures.

ACKNOWLEDGMENT

LIFE ECO-SANDFILL is co-financed by the LIFE Programme of the European Union (Grant Agreement No. LIFE15 ENV/ES/000612).

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This paper is an invited submission to Foundry Trade Journal, selected from presentations at the 73rd World Foundry Congress – organised by the Polish Foundrymen's Association on 23rd to 27th September 2018 in Krakow, Poland – and has been expanded from the original presentation.