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Influence of Modern Inorganic Binders GEOPOL® on Green Sand Mixtures

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Abstract

In collaboration with SAND TEAM, KERAMOST and the Italian foundry F.A. Spa through F.A. Engineering Srl partner of the Green Casting LIFE project, the effect of the proportion of sand from inorganic cores on the properties of green sand mixtures was investigated. The loss of tensile strength in the condensation zone was chosen as a criterion. It is usually stated that a decrease of 20% compared to the values without the addition of the studied mixture component is critical. The compressive strength and abrasion of the green sand mixtures was also attempted to be evaluated. Core mixtures with the following binders were chosen as the likely source of sand from the cores for the green sand mixtures: GEOPOL® CO_2 for carbon dioxide hardening and GEOPOL® W for hardening with the heat of the core box and blowing with hot air. It was found that GEOPOL® W had significantly less harmful effects on the properties of green sand mixture. A critical loss of strength in the condensation zone occurs only at a content of 70% of the sand from these cores and 45% in the case of the F.A. Spa green sand mixture. The abrasion tests showed, only a minimal negative effect of the sand from the cores was detected.

Keywords: Inorganic binder, Core, Green sand mixture / Bentonite sand mixture, Loss of strength in the condensation zone

1. Introduction

Recently, the foundry industry has been coming to terms with the ecological nature of its production and the impact of waste on the environment. This leads to the return of inorganic core binders. New binder systems, such as geopolymer binders [1-5], have significantly better properties than classic water glass [6-11]. In the case of classic water glass, this effect was very negative, but the very poor collapsibility of these cores "helped", so that a minimum of sand from the cores was returned to the moulding compound. One of the proposed improvements is the excellent collapsibility of the new inorganic binders (geopolymer and modified water glass). Industrially, these binders are used for cast iron, steel and light alloy castings and usually without combination with another moulding compound. Recently, however, there have been many attempts to use it for cast iron castings in green sand mixtures as well [12]. The authors of this lecture [12] mainly deal with the quality of castings (cylinder heads) in terms of deterioration of the core of the water jacket in areas with a small cross-section. In terms of the effect on the moulding sand mixture, they only state that up to 25% of the percentage of sand from disintegrated cores in the bentonite moulding mixture has not been problematic. But this means that it was necessary to add 75% of new fresh sand or harmless sand, which have not negative impact on the properties of green sand mixture, to the supply of sand from the cores. This can be a problem for intense core work.

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2. Methodology description and results

In cooperation between SAND TEAM, KERAMOST and F.A. Spa within the Green Casting LIFE project [13], the maximum usable content of the sand derived from cores that are bonded with the GEOPOL® binders was tried to find. The Green Casting Life Project (LIFE21-ENV-FI-101074439 GREEN CASTING LIFE) [13] aims to demonstrate the technical and environmental feasibility of using new inorganic binders, instead of traditional organic ones, in ferrous foundries.

The tests were carried out in two phases. Firstly, the influence of the sand from the cores on the total sand content when mixing a new green sand mixture from new fresh raw materials (new fresh sand, new fresh bentonite) was investigated.

In the second phase, the effect of recovery, using the sand from cores made with GEOPOL® W binder and the mixed bentonite used, on the operating FA Spa bentonite green sand moulding mixture was investigated.

Green sand mixtures were prepared in the sand muller MK0, Figure 1. The batch in the muller was 2000 g of sand. The mixing procedure was as follows: first, the fresh sand and water added into the muller and mixed for 1 minute, followed by the addition of fresh bentonite and additives and mixing for another 6 min.

Fig. 1. Batch sand muller MK0 for bentonite green sand

The effect on the tensile strength in the condensation zone of water was chosen as the harm assessment test for the new bentonite sand mixture, see Condensation zone strength measuring apparatus, Figure 2 c). This is because this test is generally rated as the most sensitive to contamination. For the critical deterioration criterion, a 20% decrease in this strength was used, compared to the bentonite sand mixture without the core sand content. This value was determined by calculation from measured strengths over the interval with a drop above and below 20%. The value of 20% drop was chosen on the basis of empirical experience and serves comparison of the evaluated sand. From the experience of many years of using cores made in inorganic binders, the abrasion of the test samples was also measured, Figure 2 d). However, the strength in the condensation zone has been shown to be more sensitive [14-17].

Other conventional parameters have also been monitored and measured to characterize the bentonite mixtures as moisture, compressive strength, graft strength, compactability, permeability, washable substances, LOI, methylene blue adsorption, conductivity and pH.

a)

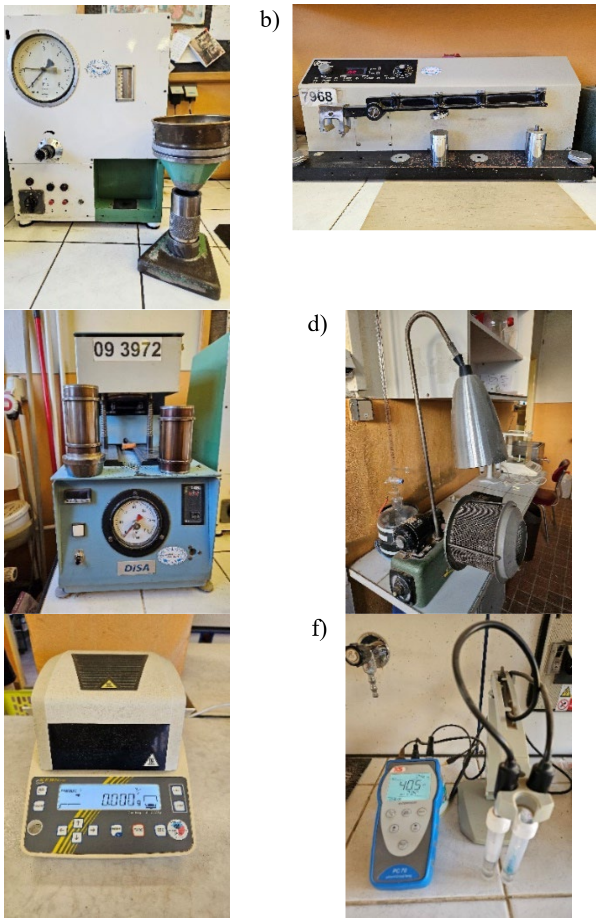

Fig. 2. Measuring equipment/apparatuses:
a) Measurement of compactability; b) Compressive and graft strength aparatus; c) Condensation zone strength measuring apparatus; d) Abrasion measuring instrument; e) Automatic drying scales for moisture measurement; f) Electrical conductivity and pH measurement

2.1. Preparation of sand from inorganic geopolymer cores in SAND TEAM

SAND TEAM supplies inorganic binders from the GEOPOL® range, which are suitable both for self-hardening mixtures and for CO_2 hardening or heat hardening [1, 2]. Core sand mixtures with the following binders were chosen as the likely source of sand from the cores for the green sand mixtures:

- GEOPOL® CO_2 for carbon dioxide hardening and GEOPOL® W for hardening with the heat from the core box and hot air blowing. Both sand mixtures were prepared in the SAND TEAM laboratory.
- BK 31 quartz sand was used as a new fresh sand (average grain size d_{50} = 0.31 mm).

Using these two technologies, the SAND TEAM prepared "sands from cores". The core mixtures were first hardened:

- GEOPOL® CO_2: hardened by blowing CO_2 for 50 seconds (at a rate of 15 litres of CO_2 per minute) or
- GEOPOL® W: by drying in a dryer at 150 °C for 1.5 hours.

The mixtures were then crushed and divided into 4 parts each, which were then subjected to thermal degradation:
- The first part remained thermally unaffected (that is, it was not heated but remained unchanged after distribution).
- The second part was heat-loaded at 800 °C for 2 hours.
- The third part was heat-loaded at 400 °C for 2 hours.
- The fourth was heat-loaded at 200 °C for 2 hours.

These 4 parts of each mixture were then homogenized. The materials obtained were then used together with fresh sand BK 31 to prepare green sand mixtures in the first phase of the tests in the KERAMOST laboratory.

2.2. Preparation of sand from inorganic geopolymer cores in F.A. Spa

In the second phase of the tests, the core sand was obtained from the tests carried out at the F.A. Spa foundry in Italy. The cores were made with the binder GEOPOL® W by heat hardening in core shop plant and the cores were put inside moulds made of green sand mixture. After casting at the F.A. Spa foundry, the residuals of cores were separated from the green sand mixture and castings, crushed into grain size material in SAND TEAM and submitted to the KERAMOST laboratory for testing.

2.3. Effect of inorganic geopolymer cores on the new bentonite sand mixture

The KERAMOST laboratory has compared the basic properties of facing moulding mixture with 7% fresh bentonite from fresh sand and with different proportions of sand retrieved from cores, produced by SAND TEAM.

BK 31 sand (average grain size $d_{50} = 0.31$ mm, sand regularity $d_{75}/d_{25} = 60.43\%$) was always used, so it was possible to assess the effect of the proportion of core mix with the same sand. It turned out that the mixture with BK 31 has completely different mixture strength – compared to the standard ST 53 used in the Czech Republic (average grain size $d_{50} = 0.27$ mm, sand regularity $d_{75}/d_{25} = 58.1\%$), Table 1.

Table 1.
Comparison of the values of the moulding sand mixture from raw fresh materials at 7% bentonite for standard ST 53 and BK 31 sand

Sand	Unit	Standard ST 53	BK 31
Moisture of the mixture	%	2.49	2.32
Compactability	%	47	46
Compressive strength	kPa	94.3	131.0
Strength in the condensation zone	kPa	3.27	4.70

The BK 31 sand showed a 39% increase in compressive strength and a 44% increase in tensile strength in the condensation zone. This result only documents the enormous influence of the new fresh sand on the strength of the facing green sand. The purpose of this work is not a justification or other analysis of these values.

Table 2 shows the measured values of moulding mixtures containing a proportion of sand from cores with a GEOPOL® CO_2 binder intended for carbon dioxide hardening. Similarly, values were also measured with the proportion of sand from cores with GEOPOL® W binder, intended for hardening with the heat of the core and blowing with hot air. The values are given in Table 3.

Table 2.
Measured values of mixtures with 7% fresh bentonite and with different proportions of sand with GEOPOL® CO_2

Observed material property	Unit	Proportion of sand with GEOPOL® CO_2			
Sand with GEOPOL® CO_2	**%**	**0%**	**25%**	**30%**	**60%**
Compactability	%	46	47	46	48
Compressive strength average	kPa	131	134	138	151
Graft strength average	kPa	33	32	30	31
Graft strength / compressive strength	---	-	0.24	0.22	0.20
Tensile strength in the condensation zone average	kPa	4.7	3.7	3.3	2.4
Loss of tensile strength in the condensation zone	%	0	23	31	49
Abrasion average	%	29	23	22	19
Methylene blue (MB) adsorption	mg MB/g	22.0	22.3	21.6	21.6
Conductivity	µS/cm	293	413	435	573
pH	---	9.94	10.08	10.02	10.21

Table 3.
Measured values of mixtures with 7% fresh bentonite and with different proportions of sand with GEOPOL® W

Observed material property	Unit	Proportion of sand with GEOPOL® W			
Sand with GEOPOL® W	**%**	**0**	**30**	**60**	**100**
Compactability	%	46	49	45	50
Compressive strength average	kPa	131	153	118	116
Graft strength average	kPa	33	35	23	22
Graft strength / compressive strength	---	0.25	0.23	0.20	0.19
Tensile strength in the condensation zone average	kPa	4.7	5.0	3.9	3.0
Loss of tensile strength in the condensation zone	%	0.0	-6.3	16.9	37.3
Abrasion average	%	29	17	27	24
Methylene blue (MB) adsorption	mg MB/g	22.0	23.7	23.7	21.7
Conductivity	µS/cm	293	370	430	540
pH	---	9.94	10.00	10.29	10.41

The results show, that sand from heat-hardened cores has a much less harmful effect (more cores can be used to the bentonite sand mixture without significantly degrading properties of the tested bentonite mixture). A 20% loss of tensile strength in the condensation zone was chosen as the criterion for determining the degree of damage caused by sand from cores, compared to values with fresh sand. The values of the 20% reduction were determined by calculation – see Figure 2 and Figure 3.

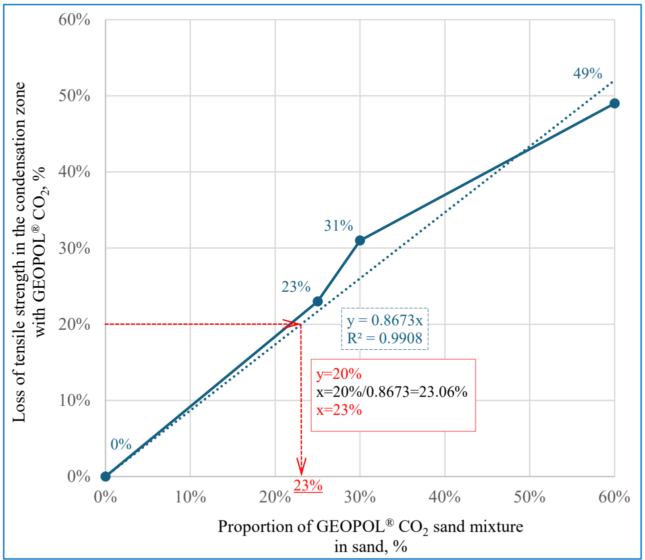

Fig. 3. Loss of tensile strength in the condensation zone at GEOPOL® CO_2

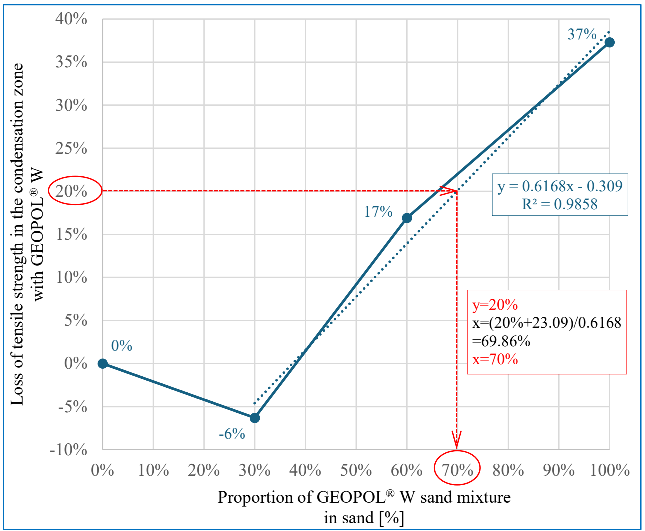

Fig. 4. Loss of tensile strength in the condensation zone at GEOPOL® W

Tensile strength in the condensation zone decreased by 20% in the mixture of cores with the GEOPOL® CO_2 binder occurred at a content of 23%, in the mixture with the GEOPOL® W binder at up to 70% of the sand content. Even at 30% share, there was an increase in tensile strength in the condensation zone by 6.3%.

A positive finding is that there was no significant increase in abrasion with either type of GEOPOL® binder.

KERAMOST has an additive at its disposal that is capable of adsorbing unwanted ions in the moulding mixture, thereby helping the bentonite against their effects. All mixtures were therefore mixed with the usual amount of this additive. This was reflected in the change in the value of the sand content from the cores when the tensile strength in the condensation zone (TSCZ) decreased by 20% (Table 4.). It can be seen, that the active additive has a beneficial effect. Its use did not result in a significant change in the measured values for new facing sand, compared to tests without the additive.

Table 4.
Effect of using a special additive

Estimation of % sand from cores at 20% drop in tensile strength in the condensation zone		
GEOPOL® CO_2	23	% of core sand
GEOPOL® CO_2 + additive	26	% of core sand
GEOPOL® W	70	% of core sand
GEOPOL® W + additive	81	% of core sand

2.4. Effect of inorganic geopolymer cores on the F.A. Spa bentonite moulding sand mixture

In the second phase of the tests, the effect of cores with only GEOPOL® W binder on the recovery of the green sand moulding mixture from the specific foundry FA Spa, Assisi was assessed/evaluated. Properties of used F.A. Spa green sand mixture, fresh bentonite, crushed grain size sand from GEOPOL® W cores are given in the Table 5. The recovery/revitalization was carried out by adding the afore mentioned sand and the supplied mixed raw bentonite in such a way that the proportion of active bentonite remained. The 11% mixed raw bentonite was added to the green sand mixture from geopolymer cores. The results obtained on the influence on the tensile strength in the condensation zone are shown in Table 6 and Figure 5 and Figure 6.

The effect of the sand from the cores themselves is greatly distorted by the completely unrealistic recovery. Nevertheless, it can be stated that the expected low deterioration of tensile strength in the condensation zone has been confirmed. Even with a 50% recovery, the tensile strength in the condensation zone there is still very high, reaching 1.9 kPa.

The loss of tensile strength in the condensation zone decreased by 20% up to 45% of the sand mixture with the GEOPOL® W binder cores. This measurement also shoved, that 10 to 25% of the geopolymer core sand increases the tensile strength in the condensation zone by more than 20%, which is about 3.3 kPa.

Table 5.
Complete properties of F.A. Spa green sand mixture and other input materials

Observed material property	Unit	Green sand mixture		Bento-nite	GEOPOL® W cores
		Wet	Dry		after casting
Moisture origin	%	3.23	1.21	8.03	-
Compactability origin	%	22	-	-	-
Moisture modified	%	3.33	-	-	-
Compactability modified	%	45	-	-	-
Permeability	u.p. SI	170	-	-	-
Compressive strength	kPa	183.2	-	-	-
Graft strength	kPa	48	-	-	-
Tensile strength in the condensation zone (TSCZ)	kPa	4.7	-	-	-
Abrasion	%	0.30	-	-	-
Methylene blue adsorption	mg MB/g	34.6	34.8	316.9	-
pH	-	10.1	10.1	10.4	10.2
Conductivity	mS/cm	568	569	636	1479
Washable substances	%	11.68	11.18	-	-
LOI	%	4.11	4	34.01	0.34
Lustrous carbon	%	0.07	0.08	1.50	-
Residue on mesh 0.063 mm	%	-	-	22.52	-

Table 6.
Tensile strength in the condensation zone (TSCZ) of F.A. Spa green sand mixture as a function of the number of cores from GEOPOL® W technology

Proportion of sand with GEOPOL® W in green sand mixture	**%**	**0**	**23**	**38**	**44**	**50**
TSCZ	kPa	2.7	3.3	2.9	1.9	1.9
Loss of TSCZ	%	0	-21	-7	30	30

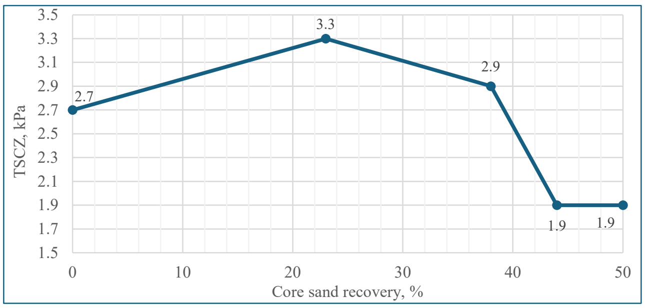

Fig. 5. Effect of sand recovery from cores on tensile strength in the condensation zone (TSCZ)

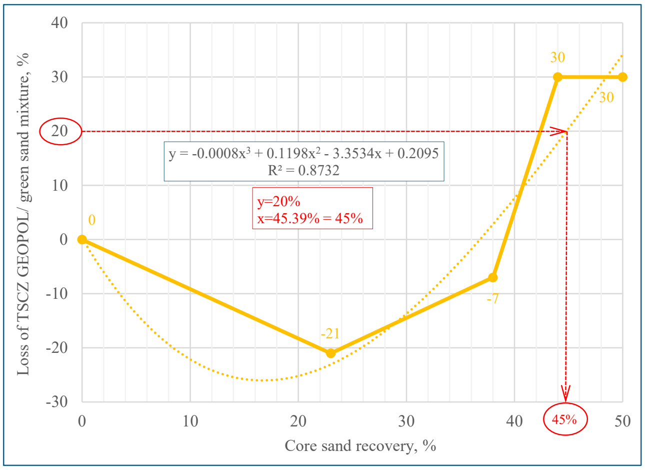

Fig. 6. Effect of sand recovery from cores on tensile strength in the condensation zone, loss of TSCZ

The compressive strength results, Figure 7 and Table 7, show linear decrease in strength from 195 kPa with increasing amount of geopolymer sand up to 26% to 145 kPa at 50% geopolymer sand in green sand mixture. The reason for the decrease in compressive strength is probably an imperfectly mixed sand mixture, due to excessive recovery.

Table 7.
Compressive strength of F.A. Spa green sand mixture as a function of the number of cores from GEOPOL® W technology

Proportion of sand with GEOPOL® W in green sand mixture	**%**	**0**	**23**	**38**	**44**	**50**
Compressive strength	kPa	195	166	156	152	145
Loss of compressive strength	%	0	15	20	22	26

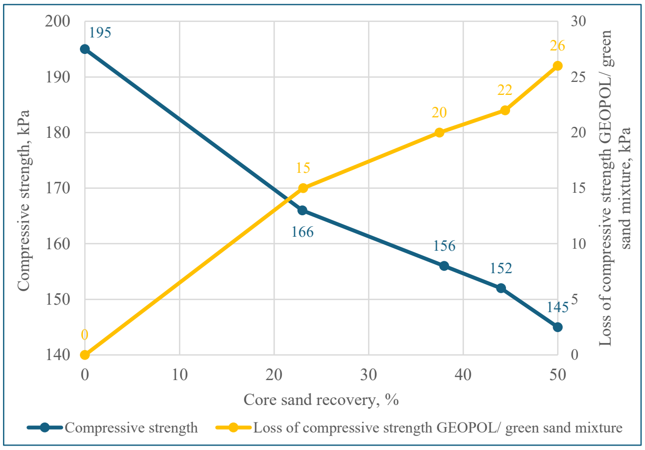

Fig. 7. Changes in compressive strength with core sand recovery

A positive finding is the abrasion behaviour. The addition of geopolymer sand does not significantly increase the abrasion of the green sand mixture. On the contrary, there is an improvement in abrasion of up to 40%, see Table 8 and Figure 8.

Table 8.
Abrasion of F.A. Spa green sand mixture as a function of the number of cores from GEOPOL® W technology.

Proportion of sand with GEOPOL® W in green sand mixture	%	0	23	38	44	50
Abrasion	%	0.340	0.201	0.224	0.268	0.313
Increasing of abrasion	%	0	-40.8	-34.2	-21.1	-7.9

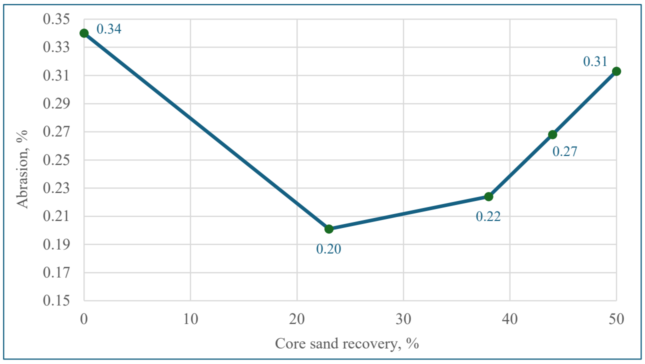

Fig. 8. Changes in abrasion with core sand recovery

3. Conclusion

From the point of view of the effect on the properties of the moulding sand mixture, the addition of sand from cores made with GEOPOL® W binder and hardened by heat is much less harmful than sand with GEOPOL® CO_2 binder, hardened by carbon dioxide.

It is possible use 23% of cores made with GEOPOL® CO_2 binder to the new green sand and even 70% of cores made with GEOPOL® W binder to the new facing green sand.

For the operational F.A. Spa green sand mixture is possible to use 45% of cores made with GEOPOL® W binder.

The addition 10 to 25% of the geopolymer core to the operational F.A. Spa green sand mixture increases the TSCZ by more than 20%.

The compressive strength results show linear decrease in strength by 26% at 50% geopolymer sand in operational F.A. Spa green sand mixture.

A positive finding is the abrasion behaviour. There is an improvement in abrasion of up to 40% in monitored addition of recovery sand to operational F.A. Spa green sand mixture.

It is now necessary to test the actual application in the foundry and thereby mainly verify the effect on the quality of the castings. The recommendations given in [16] for other core production technologies are based on the quality of the castings, not from the properties of the moulding sand.

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