ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 8
Special Issue
3/2008

103 – 106

22/3

Complex evaluation of moulding sand properties by multi-factor analysis of variance

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Received 01.07.2008; accepted in revised form 03.09.2008

Abstract

The article presents the statistical evaluation of selected properties of moulding sands with additions of various binders. A utilitarian objective of this study was to determine the possibility of using coal dust as an additive to sands to protect castings made in these sands from the burn on defects. Another objective of the study was to investigate the possibilities to eliminate the protective coatings in view of a high cost of their application. The investigations were carried out on mixtures based on silica sand with binders, i.e. P26 flocculant – a complex compound of vegetable origin, and Gitar – a waste material formed during manufacture of hydrogen cyanid, with an addition of coal dust. Applying the multi-factor analysis of variance, a complex effect of the sand chemical composition, and of the drying time and temperature on dry compression strength R_c^s was analysed

Keywords: Moulding sand, P26 and Gigtar binders, Multi-factor analysis of variance

1. Introduction

Proper choice of moulding sand is one of the most important factors in casting production. Numerous investigations carried out in foundries have proved that misfit moulding materials are the main cause of defects formed on casting surface, and as such contribute greatly to the production of rejects and reduced output of moulding lines. The process economy must also suffer due to the increased production costs. A very important role in the technology of casting production plays also the correct choice of binder and of other additives introduced to moulding sand. The task of these additives is to improve the sand properties, that is, to increase the refractoriness, to change the thermophysical behaviour of sand, and to increase the compression strength. Some additives are used as release agents improving the collapsibility and knocking out properties as well as the permeability of moulds and cores. They should also prevent the burn on defects. This study presents the results of attempts to evaluate in terms of statistics the effect that some sand components used as additives are said to have on the compression strength R_c^s of the sand mixture. The investigations were carried out on moulding sands with an addition of P26 binder and coal dust, and on the sands with Gigtar binder and coal dust. The effect of individual factors on the examined property was determined as well as an interaction that may occur between various parameters and also affect the sand compression strength. Properly calculated additions of binder and coal dust with correctly adjusted sand drying time and temperature play an important role in the increase of moulding sand compression strength, affecting also the moulding sand quality and, indirectly, the casting production cost effectiveness, the casting quality and the efficiency of moulding lines.

2. Materials and methods of investigation

The following materials were used in the investigations:

- Washed river silica sand,

- Coal dust – waste product supplied by the Institute for Chemical Processing of Coal (Zabrze).
  In investigations, ground coal dust of 0,063 mm maximum fraction was used.

Below, physico-chemical characteristics of pulverised carbonisate used in the investigations are given:

- moisture content: W^a =0,85%
- ash content: A^a = 14,67%
- volative matter content V^a = 8,53%
- granulometry:
  >3 mm - 0,0 wt.%, 3 – 2 mm - 0,2 wt.%,
  2 – 1 mm - 0,4 wt.%, 1 – 0,5 mm - 6,0 wt.%,
  0,5 – 0,2 mm - 31,5 wt.%, 0,2 – 0,1 mm - 31,9 wt.%,
  0,1 -0,06 mm - 14,0 wt.%, < 0,06 mm - 16,0 wt.%.
- carbon content in analytical state C^a = 77,9%
- hydrogen content in analytical state H^a =1,9%
- total sulphur content in analytical state S_t^a = 0,92%
- nitrogen content in analytical state N^a = 1,15%
- P26 flocculant – a multimolecule compound of vegetable origin and low molecular weight obtained by hydrolysis of starch (e.g. potatoes). Produced in powdered form, it is characterised by good solubility in cold water,

- Gigtar – waste material formed during production of hydrogen cyanide. The chemical analysis of Gigtar after baking revealed the content of carbon C^a = 62,0%; hydrogen H^a = 1,72%, nitrogen N^a = 18,63%. The product was supplied by Zakłady Azotowe in Tarnów,
- Water
  - added to sands with P26 flocculant in an amount of 8%
  - added to sands with Gigtar flocculant in an amount of 3% .

The compression tests were carried out on standard cylindrical specimens of 50 ± 0,8 mm diameter and a height of 50 ± 1,0 mm, using a versatile apparatus of LRu type. The standard cylindrical specimens were prepared in a moulding sleeve, compacting them with three rams of a laboratory LU type rammer. The compression strength was determined on standard cylindrical specimens after drying. The cylindrical specimens were dried in a laboratory drier without air circulation. The drying temperature was 413 K and 453 K; the time of drying was 30 minutes or 60 minutes. Tests were carried out on sands containing coal dust in amounts of 1%, 2%, 3% and 4%. The dry compression strength R_c^s was determined on sands of two types:

SAND I:

Composition: washed river silica sand, coal dust, **P26 binder** and 8% water.
Coal dust content in the sand: 1%, 2%, 3% and 4%
P26 binder content in the sand: 0,5%, 1%, 1,5% and 2%
Sand preparation: to silica sand the P26 binder was added and the whole was mixed in an edge runner mixer of MK-060A type for about 5 minutes. Then water solution of the coal dust was added, and the whole was mixed again for about 15 minutes.

SAND II:

Composition: washed river silica sand, coal dust, **Gigtar binder** and 3% water.
Coal dust content in the sand: 1%, 2%, 3% and 4%
Gigtar binder content in the sand: 5%, 6%, 7% and 8%
Sand preparation: to silica sand the Gigtar binder was added and the whole was mixed in an edge runner mixer of MK-060A type for about 5 minutes. Then water solution of the coal dust was added, and the whole was mixed again for about 20 minutes
For each sand composition and for each drying time and temperature three measurements of the compression strength were taken.
The data on the compression strength R_c^s of the examined sand were introduced to a licensed version of Excel calculation sheets prepared by Microsoft, to be implemented next in a STATISTICA v.7.1. PL program made by StatSoft.
In statistical analysis, the level of significance (error of the 1st kind) of $p(\alpha) < 0{,}05$ was accepted [1].
In statistical evaluation, the analysis of variance was carried out on a general ANOVA/MANOVA software [2].
The general procedure adopted in variance analysis consists of the three main steps:

1. The fundamental notion is that of variance, which for the n number of observarions x_i=1,...., n is defined by formula: $\sum_{i=1}^{n}\left(x_i-\overline{x}\right)^2$ where $\overline{x}$ is the arithmetic mean of observations. Hence the variance is defined as a sum of the squared deviations of the possible values of the individual observations from the expected mean.
2. The total variance is divided into variances originating from different factors examined in the experiment. For example, if k factors are considered, then the following division applies: $SS_{całkowita} = SS_i + ... + SS_k$, where SS_i is the variance ascribed to the i-th factor. Of course, also the variances related to random factors (random errors) are considered.
3. The individual sums of the squares are divided by the, so called, "degrees of freedom". The obtained quotients are called „mean squares" (in abbreviated form denoted as MS). Comparing the mean squares obtained for the respective factors with the mean square of an error one can decide if the effect of a given factor on the results of the experiment is significant, or if it is of purely random character.

Analysing the obtained results of investigations, an attempt was made to answer the following questions:

- Are there any differences in the average value of R_c^s caused by the differences in coal dust addition ?
- Are there any differences in the average value of R_c^s caused by the differences in drying time and temperature ? These two questions reflect our interest in the two factors that can be denoted as „coal dust" and „temperature".

Moreover, an answer to one additional question was sought:

- Is there any interaction between the factors called „coal dust" and „temperature" ?

An answer to these questions can be obtained by application of the multi-factor analysis of variance (MANOVA). This method is a tool that enables the effect of interaction to be detected. Considering each factor separately it is possible to state an interaction between all the examined factors. An interaction between two factors tells us in what way the effect of the former factor will depend on the level of the latter factor. If the same level is obtained, it means that there is no interaction. If the levels differ, it means that there is an interaction between two factors.

From the above remarks it follows that multi-factor ANOVA is a much more versatile tool, offering more possibilities, and as such it can be effectively applied in studies of the complex problems. It is also worth noting that if an interaction does not occur, the factors are said to be “additive”.

3. Results

Table 1 shows the results of ANOVA test for the main effects occurring in sand with P26 binder.

Table 1.
The results of ANOVA test for the main effects occurring in sand with P26 binder

Parameter	SS	MS	F	p
Free term	154,666	154,666	729,372	0,0000
Coal dust [%]	7,847	2,616	12,335	0,0000
Binder	19,962	6,654	31,380	0,0000
Temperature	11,221	11,221	52,914	0,0000
Time	24,016	24,016	113,255	0,0000
Error	38,806	0,212		

As proved by the results of the statistical evaluation of the main effects, the statistically significant effect on the examined dependent feature R_c^s shall have all the investigated factors, i.e. coal dust content, binder content, and the time as well as temperature of the sand drying, but among them the most significant main effect shall have the time of drying.
To find an interaction between the effects of the examined input characteristics on R_c^s , an ANOVA (MANOVA) test was carried out for the factorial effects (Table 2).

Table 2.
The results of ANOVA test for the factorial effects occurring in sand with P26 binder

Parameter	SS	MS	F	p
Free term	154,666	154,666	11164,819	0,0000
(1) Coal dust [%]	7,847	2,616	188,814	0,0000
(2) Binder	19,962	6,654	480,340	0,0000
(3) Temperature	11,221	11,221	809,975	0,0000
(4) Time	24,016	24,016	1733,639	0,0000
Coal dust [%]* Binder	5,442	0,605	43,648	0,0000
Coal dust [%]* Temperature1	10,457	3,486	251,627	0,0000
Binder*Temperature	0,665	0,222	15,994	0,0000
Coal dust [%]* Time	0,970	0,323	23,335	0,0000
Binder* Time	7,263	2,421	174,763	0,0000
Temperature1* Time	0,118	0,118	8,501	0,0000
Coal dust [%]*Binder*Temp	4,801	0,533	38,509	0,0000
Coal dust [%]*Binder*Time	2,541	0,282	20,381	0,0000
Coal dust [%]*Temp*Time	0,482	0,161	11,590	0,0000
Binder*Temperature*Time	2,898	0,966	69,741	0,0000
1*2*3*4	1,396	0,155	11,197	0,0000
Error	1,773	0,014		

As proved by the results of the statistical evaluation, the most significant effect on R_c^s of the sand with P26 binder shall have the following factors, enumerated in decreasing order of the significance of effect: time and temperature of drying, binder content, and coal dust content/drying temperature interaction (Figs.1, 2).

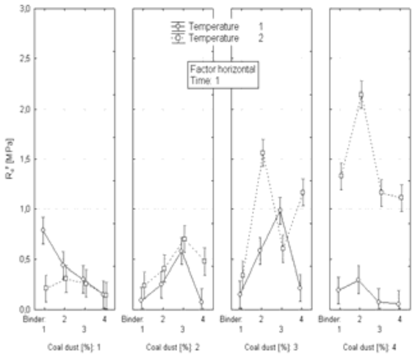

Fig. 1. Effect of coal dust content, P26 binder content and drying temperature on R_c^s of the examined sand with the drying time of 30 min

Adopted coding of variables: Coal dust: 1 – 1%, 2 – 2%, 3 – 3%, 4 – 4%;
P26 binder: 1 – 0,5%, 2 – 1%, 3 – 1,5%,4 – 2%;
Drying temperature: 1 – 413 K, 2 – 453K;
Drying time: 1- 30 min, 2 – 60 min

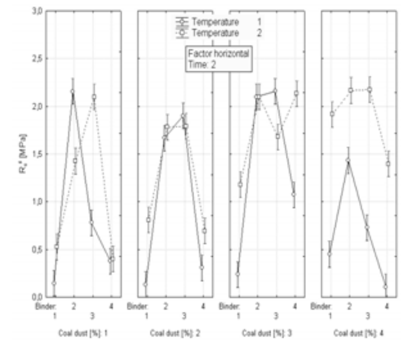

Fig. 2. Effect of coal dust content, P26 binder content and drying temperature on R_c^s of the examined sand with the drying time of 60 min

Coding of variables as in Fig. 1

Table 3 shows the results of ANOVA test carried out for the main effects, while Table 4 shows the results of ANOVA (MANOVA) test for the factorial effects occurring in sand with Gigtar binder.

Table 3.
The results of ANOVA test for the main effects occurring in sand with Gigtar binder

Parameter	SS	MS	F	p
Free term	54,923	54,923	605,127	0,0000
Coal dust [%]	1,324	0,441	4,863	0,0028
Binder	1,261	0,420	4,632	0,0038
Temperature	0,280	0,280	3,083	0,0808
Time	18,161	18,161	200,092	0,0000
Error	16,610	0,091		

As proved by the results of the statistical evaluation of the main effects, the statistically significant effect on the examined dependent feature R_c^s (Table 4) of the sand with Gigtar binder shall have all the investigated factors, i.e. coal dust content, binder content and the time of sand drying, but among them the most significant main effect shall have the time of drying. The temperature of the sand drying did not reveal any statistically significant effect on the examined characteristic of R_c^s.

Table 4.
The results of ANOVA test for the factorial effects occurring in sand with Gigtar binder

Parameter	SS	MS	F	p
Free term	54,923	54,923	14252,245	0,0000
(1) Coal dust [%]	1,324	0,441	114,528	0,0000
(2) Binder	1,261	0,420	109,085	0,0000
(3) Temperature	0,280	0,280	72,616	0,0000
(4) Time	18,161	18,161	4712,667	0,0000
Coal dust [%]* Binder	5,486	0,610	158,184	0,0000
Coal dust [%]* Temperature1	0,346	0,115	29,962	0,0000
Binder*Temperature	0,687	0,229	59,383	0,0000
Coal dust [%]* Time	1,170	0,390	101,197	0,0000
Binder* Time	0,874	0,291	75,567	0,0000
Temperature1* Time	0,139	0,139	36,125	0,0000
Coal dust [%]*Binder*Temp	1,503	0,167	43,335	0,0000
Coal dust [%]*Binder*Time	3,891	0,432	112,199	0,0000
Coal dust [%]*Temp*Time	0,188	0,063	16,230	0,0000
Binder*Temperature*Time	0,347	0,116	30,018	0,0000
1*2*3*4	1,485	0,165	42,828	0,0000
Error	0,493	0,004		

The most significant effect on R_c^s of the sand with Gigtar binder shall have the following factors, enumerated in decreasing order of the significance of effect: time of drying and coal dust content/binder content interaction (Figs.3, 4).

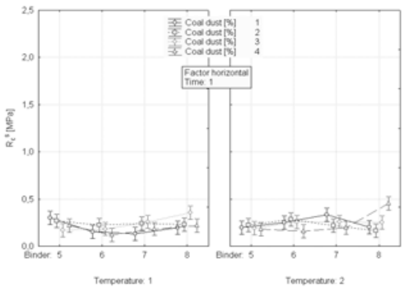

Fig. 3. Effect of coal dust content, Gigtar binder content and drying temperature on R_c^s of the examined sand with the drying time of 30 min.

Coding of variables as in Fig. 1

Gigtar binder: 5 – 5%, 6 – 6%, 7 – 7%, 8 – 8%;

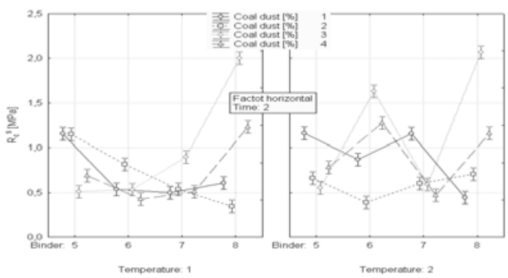

Fig. 4. Effect of coal dust content, Gigtar binder content and drying temperature on R_c^s of the examined sand with the drying time of 60 min.

Coding of variables as in Fig. 1 and Fig. 4

4. Summary and conclusions

In the sand with Gigtar binder the most significant main effect has the time of drying. The sand drying temperature has proved to have no statistically significant effect on the examined characteristic of R_c^s. As proved by the results of the statistical evaluation, the most significant effect on R_c^s of the sand with Gigtar binder have the following factors, enumerated in decreasing order of the significance of effect: time of drying and coal dust content/binder content interaction. Considering the results of an interaction between all the input factors that are said to affect the compression strength R_c^s of the examined sand, the highest value of the effect was obtained with the content of coal dust reaching about 3% and the content of Gigtar binder reaching about 8%, while the time and temperature of drying should be kept at a level of 60 minutes and 453K, respectively, the temperature of the sand drying having much weaker effect on the examined property. In the sand with P26 binder the most significant main effect also had the time of drying. The results of the investigations show us that the strongest effect on R_c^s of the sand with P26 binder have the following factors, enumerated in decreasing order of the significance of effect: time and temperature of drying, and coal dust content/drying temperature interaction. Considering the results of an interaction between all the input factors that are said to affect the compression strength R_c^s of the examined sand, the highest value was obtained with the content of coal dust reaching about 4% and the content of P26 binder reaching about 1.5%, while the time and temperature of drying should be kept at a level of 60 minutes and 453K, respectively, Methodology suggested in this study allowed to assess the property of moulding sand. The kind and the amount of applied binders can constitute an alternative solution in the case of complicated cores. The amount of applied coal dust does not exceed value applied in the industrial practice. The mechanism of synergic influence coal dust with other binders is an object of other studies.

References

[1] Maliński M., Szymszal J.: Modern mathematical statistics in calculation sheets for the medical science Wyd. ŚAM Katowice 1999 (in Polish).

[2] Stanisz A.: An easy course of statistics. Tom II, Wyd. StatSoft. Kraków 2007 (in Polish).