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INVESTIGATION OF COGS DEFECTS REASON IN GREEN SAND MOULDS

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The parameters during the moulding process of green sand directly affect casting quality. In-sufficient compaction can result in rough casting surfaces and even breakage. Too much compaction requires more energy, can cause casting defects due to low gas permeability and break of cogs and causes more wear on the pattern and equipment.

Depending on the moulding process parameters, the properties of the moulding sand and the geometry of the pattern, different regions in the mould experience different cohesion and adhesion forces resulting in varying mould properties. The effect of different moulding parameters was examined by small compaction sensors and a new measuring device for the determination of cohesion in the cog area and adhesion forces at the contour of cog pattern. By optimizing of moulding parameters it is possible to produce casting without cog breaking and high surface quality. These results allow foundry personnel to monitor, adjust and optimise the moulding process.

Keywords: mouldmaking, compaction, mould sand, quality, sensor, casting defect, cohesion, adhesion

Parametry procesu formowania z zastosowaniem mas klasycznych bezpośrednio wpływają na jakość odlewów. Niewłaściwe zagęszczenie może być przyczyną dużej chropowatości powierzchni odlewów a nawet uszkodzeń form. Zbyt duże zagęszczenie wymaga większych nakładów energetycznych i może powodować wady odlewów spowodowane małą przepuszczalnością, oberwaniem garbów (występów) form, a także jest przyczyną zwiększonego zużycia oprzyrządowania modelowego.

W zależności od parametrów procesu formowania oraz właściwości masy formierskiej w różnych obszarach formy występują zróżnicowane wartości sił adhezji i kohezji wywołujące zmienne właściwości formy. Wpływ zróżnicowanych parametrów formowania był badany przy użyciu małych czujników zagęszczenia oraz nowego urządzenia do określenia sił kohezji w obszarze garbu formy oraz sił adhezji na powierzchni modelu odwzorowującej wnękę. Optymalizacja parametrów formowania umożliwia eliminację wad odlewów spowodowanych oberwaniem garbów oraz otrzymanie odlewów o wysokiej jakości powierzchni. Przedstawione wyniki umożliwiają personelowi odlewni monitorowanie, nastawianie parametrów i optymalizowanie procesu formowania.

Introduction and problems

The quality of castings produced by clay bonded sand depends strong on the compaction of moulding sand during the production of mould. For this kind of casting production the process of mould production is as well important how the processes of mould filling, solidification and cooling [1-4]. When the production of casting is started, then the foundryman must decide a lot of questions. Despite the good experiences the moulding technology is developed often by trail-and-error-method. It needs many time and cost. The problems of the moulding technology are:

a) lifting of difficult mould parts (cogs)

b) distance between the patterns and between the pattern and the flask wall

c) choice of the optimal properties of the moulding sand

d) choice of the flask height

e) mass of the moulding sand.

Furthermore, the modern moulding machines permit a compaction of the moulding sand by different processes of compaction: squeezing. air-flow-squeezing, impact, preimpact or impact in combination with squeezing [15-18]. Also in this field the foundryman has a lot of questions:

a) choice of processes or combination of processes

b) effect duration of compaction

c) order of different processes.

In the present we have not the possibility to use clear defined knowledge for the answer to these questions and the development of the moulding tech-

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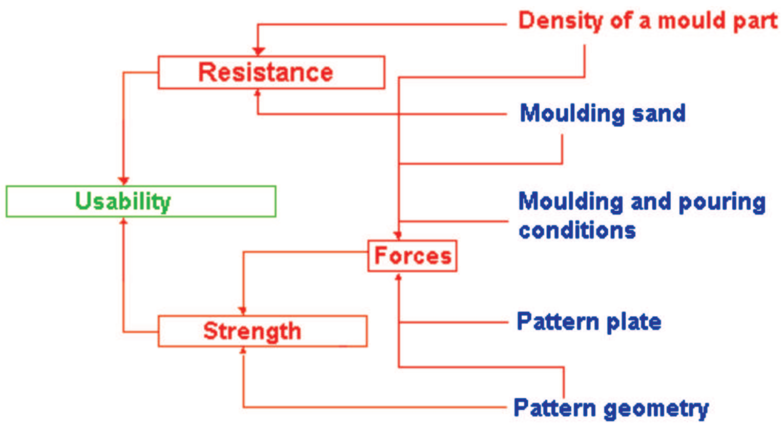


Fig. 1. Parameters for the determination of the usability of a mould [18]

nology based on the experiences of the foundryman. The main question is: "Do resisting the moulds or the parts of moulds the different strength, e. g. lifting of cogs, rollover and transport of the mould, coresetting, as-semble of mould, filling of melt and shrinkage during the solidification and cooling?". In order to produce quality castings the mould must meet all technological requirements.

In the theory of strength or in the theory of steel construction there are safety criterions for the determination of the usability of the detail or the steel construction.

$$\frac{\sigma_{\mathrm{vorh}}}{\sigma_{\mathrm{zul}}} \leqslant 1 \qquad \frac{S_d}{R_d} \leqslant 1$$

(Mechanical engineering) (Steel construction)

The equations show the formula for the estimation of safety criterions. When the relationship is lower 1, then the detail or the steel construction can be used without danger of destruction. For the creation of scientific connection between above mention parameters it is necessary to declare the mould as detail for the building of the casting and to proof the usability by the relationship of strengths and resistance of the mould.

Considering the parameters the Fig. 1 shows the connection between the resistance of the mould independent on the mould density and properties of moulding sand. If this both parameters are enlarging to the moulding and pouring conditions and the position of the patterns on the pattern plates, then it is possible to determine forces, which are occurred during the using of the mould. Considering the pattern geometry we can estimate the strength for each part of the mould. The compare between strength and resistance of the mould gives the proof of usability of the mould. In this way it is possible to assess the mould quality before pouring.

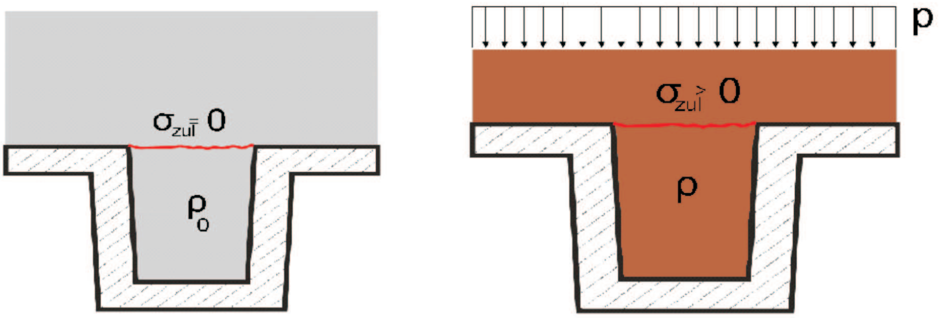
Cog break as casting defect

At the production the mould a cog break (Fig. 2) during the lifting of flask from the pattern plate can cause casting defects.

Fig. 2. Cog break at the mould caused by lifting of flask from the pattern plate

This defect occurs when adhesion forces between the cog and pattern plate are higher than cohesion forces of the moulding sand inside the cog area. Both effects result from the compaction of the moulding sand inside the pattern plate contours as well as inside the cog area. During the filling process of the moulding sand into the flask neither in cog area nor inside the cog contour strength occurs because the moulding sand is not compacted (Fig. 3).

For the cog shown in Fig. 4 Schröder, A. [5, 6] gives the following mathematical relation for calculation of a moulds usability property but in his works the experimental validation is not provided [7-14].



a) Moulding sand filling b) After compaction of sand

Fig. 3. Strength at the pattern contour and at the cog breaking area

$$RmA(x) = SBR[G(x) + R(x) + T(x) + S] \quad (1)$$

In which:
Rm – medial tensile strength
A(x) – cross section area of the cog
SBR – cog break safety
G(x) – gravitational force (cog)
R(x) – friction force (cog)
T(x) – inertial force (cog)
S – suction force (cog)
x – distance of potential cog break from cogs ground surface

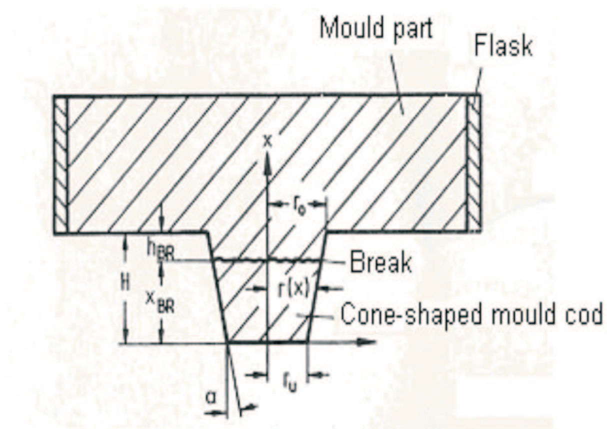


Fig. 4. Cone-shaped mould cog

As shown in Fig. 4 the cohesion force in the cog area has to conquer the adhesion forces holding it into the pattern to prevent a cog break. The cohesion force F_{Co} is described by $\mathbf{F_{Co} = \sigma_{Co} \cdot \frac{\pi}{4} \cdot d^2}$ and the adhesion force equals $\mathbf{F_{Ad} = \sigma_{Ad} \cdot \left[\left(\frac{\pi}{4}\right) \cdot d^2 + \pi \cdot d \cdot h\right]}$.

Under the condition that the cog diameter equals its height, that means d = h, so it follows from the above

$$\frac{\mathbf{F_{Co}}}{\frac{\boldsymbol{\pi}}{\mathbf{4}} \cdot \mathbf{d^2}} \geqslant \frac{\mathbf{F_{Ad}}}{\frac{\boldsymbol{\pi} \cdot \mathbf{d^2}}{\mathbf{4}} + \boldsymbol{\pi} \cdot \mathbf{d} \cdot \mathbf{h}}. \quad (2)$$

By multiplying both sides with $\pi/4 * d^2$ the relation $F_{Co} \geqslant 1/5 \cdot F_{Ad}$ results or rather $5 \cdot F_{Co} \geqslant F_{Ad}$. This means that the cohesion force of the moulding sand inside the cog area must be greater fivefold of adhesion force of the moulding sand at the contour of pattern to be able to lift the cog out of the contours of the pattern plate. The adhesion force $F_{Ad} = f(\rho, p, VD, \mu, ..)$ and cohesion force $F_{Co} = f(\rho_o, p, VD, ..)$ are depending on density ρ, pressure p, compactibility VD, coefficient of static friction μ. This means that both forces are depending on parameters of the moulding sand and the pattern geometry.

Multi-Compact-Moulding Machine

At the Institute of Mechanical Engineering of TU Bergakademie Freiberg investigations were made to evaluate adhesion forces of the moulding sand at the cog contour and cohesion forces of the moulding sand in the cog area.

Fig. 5. Small Multi-Compact-Moulding-Machine

For these experiments a moulding machine with a flask format of 500×400×200 mm and a sand filling frame of 150 mm was constructed, built and used (Fig. 5). The moulding sand compaction took place by the multiple stamp press as shown in Fig. 6.

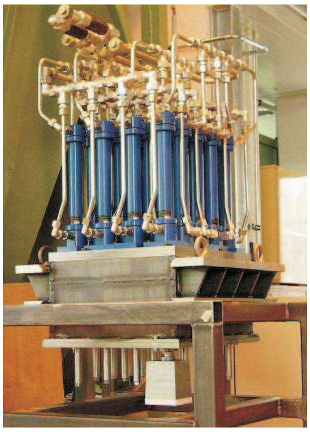


Fig. 6. Multiple stamp press device with hydraulic control

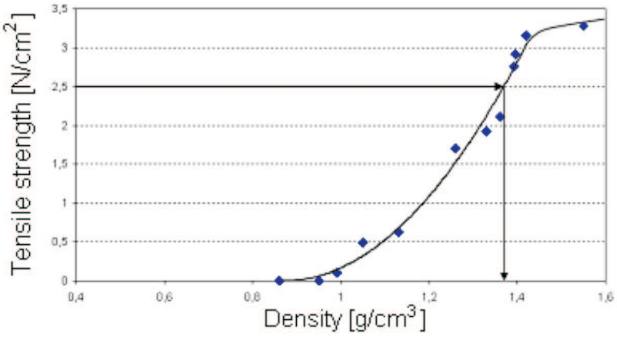


Fig. 8. Correlation between density and tensile strength

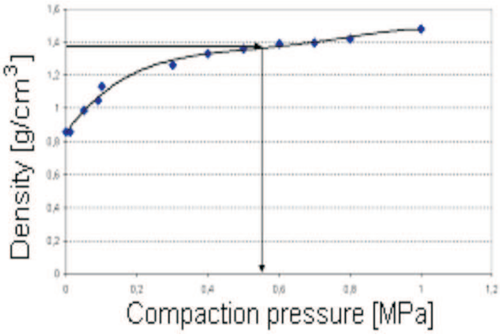


Fig. 9. Correlation between density and compaction pressure

Development of a force measuring method

The cohesion force is important for cog break behaviour. To measure these force a device was installed which is shown in Fig. 7. By the use of a muff the load cell is fixed at the bottom pattern plate carrier and connected with the pattern plate by a load transmission screw. The connection is not carried out directly but by use of a cog pattern holder which is inserts into the pattern plate and has a limited vertical movability. In this base body the real cog patterns are installed and fixed with screws. It is possible to install several pattern materials and geometries (angle, length, height).

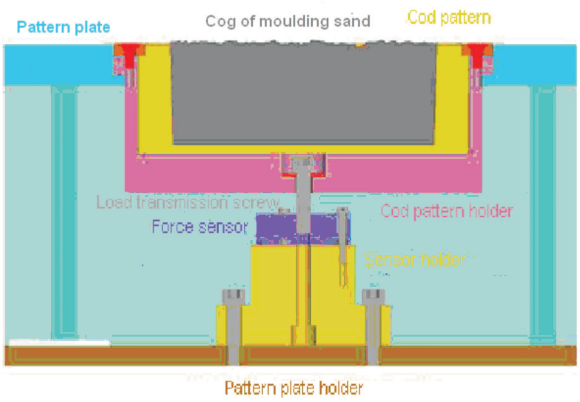


Fig. 7. Adhesion and cohesion forces measuring device

To evaluate the strength of the moulding sand in the cog area laboratory tests were made to investigate the correlation between density and tensile strength.

It is to say that with increasing density the tensile strength is rising and goes to maxima (Fig. 8). A defined density is necessary to avoid breaks in the cog area. Under praxis conditions this density is influenced by the pressure value in the cog area (Fig. 9).

The density in the cog area is influenced by compaction pressure and compactibility of moulding sand and it can be measured directly by a density sensor developed by the Institute of Mechanical Engineering. This sensor was installed in the pattern plate when moulds were produced (Fig. 10).

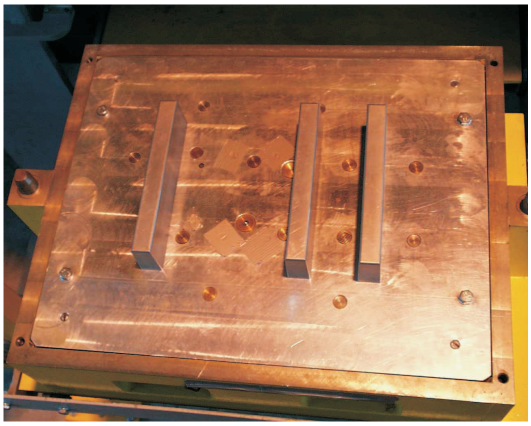


Fig. 10. Density sensor in the pattern plate

During the tests correlations between cohesion and adhesion forces influenced by the geometric parameters length, height and draft angle of the pattern were investigated. As additional variable the compaction pressure was included. The width of the cog was constant. The compactibility was adjusted by 40% and the lifting velocity at 15 mm/s. The variation of the test parameters was made by the use of experimental design (Tab. 1). As pattern material the synthetic material PUR was used.

TABLE 1

Test conditions for the investigation of cohesion and adhesion forces

	Compaction pressure	Length	Height	Angle
Dimension	bar	mm	mm	O
Transformation	x_1	x_2	x_3	x_4
Main level (0)	10	90	45	1.5
Variation	2	30	5	0.5
Upper level (-1)	8	60	40	1
Higher level (+1)	12	120	50	2

The output of the statistic analysis of the results (Tab. 2) was the following mathematical polynomial:

$$y = 102,5 + 16,75x_1 - 1,0x_2 - 3,625x_3 - 0,4x_4 \\ +3,75x_1x_2 - 4,625x_1x_3 - 2,0x_1x_4 - 1,5x_2x_4 \\ +3,125x_2x_3 - 5,875x_3x_4$$

The results show that the length as well as the height of the cog in the chosen dimensions has no essential influence on the forces. That is the reason why the values in the diagram of Fig. 11 were adjusted to the values of the main level: length of the cog: 90 mm and height of the cog: 45 mm. This diagram shows that the draft angle in the chosen area between 1° and 2° also has no essential influence to the forces. The main influence has the compaction pressure whereas an increased compaction pressure causes higher forces that is to say it is easier to lift the cog with a high quality.

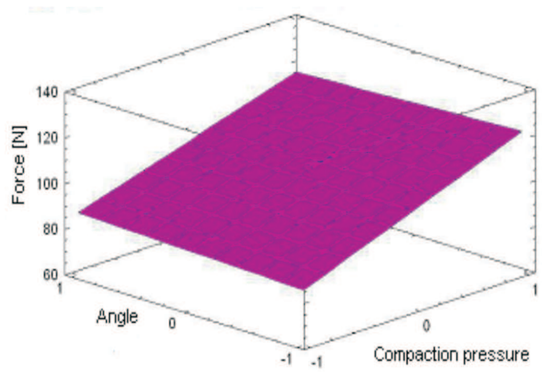


Fig. 11. Correlation between forces influenced by the draft angle and compaction pressure

At the small size moulding machine additional pressure sensors were installed to measure the effective pressure in the cog area and at the bottom of the cog (Fig. 12) by different compaction pressure.

The correlation between the compaction pressure and the effective pressure in the cog area and on the bottom of cog is shown in Fig. 13.

TABLE 2

Results of forces measuring

Experimental-number	x_1	x_2	x_3	x_4	Force [N]	Cog break
1	–1	–1	–1	–1	83	yes
2	+1	–1	–1	–1	119	yes
3	–1	+1	–1	–1	85	no
4	+1	+1	–1	–1	116	no
5	–1	–1	+1	–1	86	yes
6	+1	–1	+1	–1	122	yes
7	–1	+1	+1	–1	83	no
8	+1	+1	+1	–1	130	no
9	–1	–1	–1	+1	125	no
10	+1	–1	–1	+1	114	no
11	–1	+1	–1	+1	83	no
12	+1	+1	–1	+1	124	no
13	–1	–1	+1	+1	68	no
14	+1	–1	+1	+1	111	no
15	–1	+1	+1	+1	73	no
16	+1	+1	+1	+1	118	no

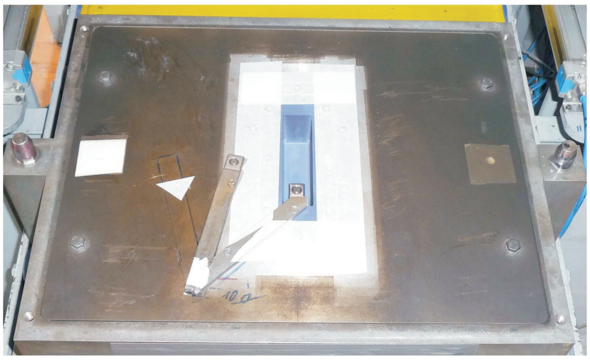


Fig. 12. Pressure sensors in the cog area and in the bottom of cog

Fig. 14. High quality casting

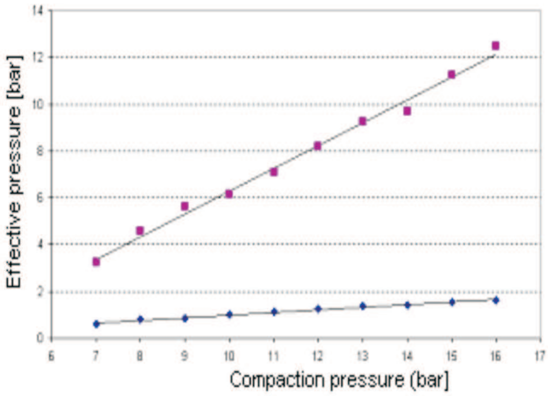


Fig. 13. Correlation between effective pressure in different cog areas and compaction pressure

As shown in Fig. 13 the measured effective pressure in the cog area (■) is significant higher than the effective pressure at the bottom of the cog (■) and also increases faster with increasing compaction pressure.

At the compaction pressure of 12 bar the difference is 7 bar, it means, that the moulding sand in the cog area is compacted fivefold higher than the moulding sand at the bottom of cog. It is the reason for the developing of a high cohesion force in the cog area and for the overcoming of the adhesion force in cog pattern contour. The cog is lifted with a high quality.

To test the usability of the cog during the casting process the cog was moulded into a hollow shape of a drag (166 mm length, 72 mm width, and 66 mm height). This hollow space was filled with melt by a gating system. The gating was placed exactly vertical and centric in relation to the cog axis to realize a sidewise and central flow against the cog.

In Fig.14 the produced casting is shown. It is to say that the strength of the cog was sufficient to resist the erosion stress.

The investigation have shown, that casting without defects can been produced by optimization of the moulding conditions.

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