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IDENTIFICATION AND QUANTIFICATION OF RAW MATERIALS DURING DESIGNING OF CAST PRODUCING PROCESS

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Is investigated the possibility to be accounted the raw material's quantity for each casting on the basis of design draft and mass of casting. To precisely determine the quantity of raw materials is necessary to technological procedure is preliminary accomplished. This task can be reached if correlations between kind of castings, shape complexity of castings, relations between total and net mass of castings, relations between mass of cores and mass of net casting will be established, with all respect toward applied technology and production methods of cores, the molding box and models.

Key words: *production design ing, raw material, foundry*

Identifikacija i kvantifikacija materijala izrade tijekom projektiranja proizvodnje odljevaka. Istražena je mogućnost izračuna materijala izrade tijekom projektiranja proizvodnje odljevaka na osnovi konstrukcijskog nacrta i poznate neto mase odljevka. Utvrđen je postupak za identifikaciju i kvantifikaciju materijala izrade odljevaka tijekom projektiranja proizvodnje odljevaka. Postavljeni cilj moguće je postići, ako se uspostave korelacije (odnosi) između složenosti oblika odljevka, vrste odljevka, odnosa bruto i neto mase odljevka, odnosno mase jezgri i neto mase odljevka, sve to uz uvažavanje primijenjene tehnologije i postupaka izrade jezgri, kalupa i modela.

Ključne riječi: *projektiranje proizvodnje, materijal izrade, ljevaonica*

INTRODUCTION

The manufacturing program of Torpedo's iron foundry had iron castings from 0,5 - 530 kg. It is a second class iron foundry [1] regarding the mass and dimensions of castings. Producing program is mainly thin-wall engine castings for engines and parts of tractors. This is a middle capacity foundry with yearly production of 6500 tones of castings [1]. The goal is to identify the raw materials and to account their quantity for each casting on the basis of design draft and mass of casting. For accurate determining of manufacture including the raw materials quantity is necessary the technological procedure will be preliminary accomplished [2].

All this has to be adjusted with plans and terms of production process [3]. This approach gives to foundries an opportunity to be involved in the integral application of Simultaneous Engineering from designing of product to its warehousing as a partner [4]. With this the foundries put their knowledge about production process and demands to designers for the using of CAD/CAM/CAE technology, fast producing of the new products, central data managing [5]. Product characteristics are important at all levels, moreover, suitability of various producing planning and control methods depend on the demand, product and manufacturing characteristics that could be changed by a PDPs (product development projects), [6].

DETERMINATION OF KIND AND QUANTITY OF RAW MATERIALS IN FOUNDRIES PRODUCTION CYCLE

Procedure for identification and quantification of manufacturing materials during the designing process of casting production will be defined. This task can be reached if correlations between kind of castings, shape complexity of castings, relations between total and mass of net casting, relations between mass of cores and mass of net casting could be established and all that regarding the applied technology and the production methods of cores, the molding box and models. Generally, next formula can be obtained:

$$G_k = G_\mu + G_f + G_i, \ /\text{kg} \quad (1)$$

where:

G_k - the mass of molding box without weight of metal frame,

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G_μ - the mass of gross metal insert,
G_f - the mass of sand form,
G_i - the mass of core.

Only one known value on disposal is the mass of net casting (the volume of model multiply with the specific density of casting) which in the following calculation for mass of gross metal insert can be used:

$$G_\mu = G_n \times K_m, \ /\text{kg} \qquad (2)$$

where:

G_n - the mass of net casting,
K_m - the factor of metal, that depends on a whole sequence of factor affecting the size and the mass of riser.

The Mass of cores from (1) can be expressed as:

$$G_j = G_n \times K_j, \ /\text{kg} \qquad (3)$$

where:

K_j - the factor of core, depending on the variables affecting the mass of core.

The mass of sand's form (molding sand) can be determined as:

$$G_f = G_n \times K_f, \ /\text{kg} \qquad (4)$$

where:

K_f - the factor of molding sand that depends on the factors K_m and K_j.

If (2), (3) and (4) are introduced in (1), can be obtained:

$$G_k = G_n \times (K_m + K_j + K_f). \ /\text{kg} \qquad (5)$$

For the solving of expression (5) the all influence factors which determine the factors K_m, K_j and K_f regarding the gross metal insert, molding sand and core in relation to the net mass of casting have to be identified and quantified. Molding box volume is defined as:

$$V_k = A \times B \times C = \text{const.}, \ /\text{m}^3 \qquad (6)$$

where:

V_k - the volume of molding box,
A - the width of molding box,
B - the length of molding box,
C - the height of molding box.

For volumes relationships is valid:

$$V_n = V_m + V_f + V_j, \ /\text{m}^3 \qquad (7)$$

where:

V_n - the volume of all materials in the molding box = V_k,
V_m - the volume of metal insert,
V_f - the volume of molding sand,
V_j - the volume of all cores.

The minimal size of molding box, considering the size of cast which dimensions are specified with the draft, during technological process designing phase of cast can be determined. According to (1), the minimal dimensions of molding box can be defined. The volume of molding box V_k will be defined by this. By means of (8) and (9) the volumes of metal and core can be solved:

$$V_m = \frac{G_m}{\rho_m}, \quad /\text{m}^3 \qquad (8)$$

$$V_j = \frac{G_j}{\rho_j}, \quad /\text{m}^3 \qquad (9)$$

where:

ρ_m - the density of metal,
ρ_j - the density of core's sand.

The volume of sand can be obtained as:

$$V_f = V_k - (V_m + V_j) \ /\text{m}^3 \qquad (10)$$

i.e.

$$G_f = V_f \times \rho_f, \ /\text{kg} \qquad (11)$$

where:

ρ_f - the density of pressed molding sand.

BASIC PARAMETERS OF CASTINGS

All influential factors determining the basic parameters of casting have to be identified and analyzed.

The net mass of casting

The net mass of casting means the mass of casting on the end of manufacture cycle without any technological supplements. Beside constant characteristics, i.e. shape of casting and numbers of models on model's plate, the bigger net mass of casting causes the coefficients K_m and K_j be smaller and opposite. If the producing program is divided on seven mass groups regarding mass of net casting the quantification of coefficients K_m and K_j will be established easier, Table 1.

Table 1. **Classification of net castings regarding their mass**
Tablica 1. **Podjela odljevaka prema neto masi**

Class No	Size of mass	Mass of net casting / kg	Mark of mass group of casting
1	Very light	For 5	g_1
2	Light	6 - 10	g_2
3	Light middle	11 - 20	g_3
4	Middle	21 - 40	g_4
5	Heavy middle	41 - 80	g_5
6	Heavy	81 - 200	g_6
7	Very heavy	Over 200	g_7

The configuration of casting

The classification of castings toward several parameters were performed, and they are: the relation between the length (*l*) and diameter of casting (*d*), the number of casting surface that will be threatened (from 1 to 6), the number of cores (from 1 to 10), Table 2. The classification of castings according to the configuration and basic shape of castings in eight groups were performed. If the complexity of casting's shape and configuration the values of coefficients have been raised K_m and K_j, will be increased.

Table 2. **Classification of casting according to: *l/d* rate, the number of processed casting surfaces and the number of cores per casting**
Tablica 2. **Klasifikacija odljevaka prema odnosu: *l/d*, broju obradivih površina i broju jezgri po jednom odljevku**

Casting	The number of processed casting surfaces					
The number of cores per casting	1		2		3	
	$l/d < 3$	$l/d > 3$	$l/d < 3$	$l/d > 3$	$l/d < 3$	$l/d > 3$
0 - 1	K1	K2	K1	K2	K1	K3
2 - 3	K1	K2	K1	K2	K1	K3
4 - 5	K1	K4	K1	K4	-	K4
6 - 7	-	-	-	-	-	-
8 - 9	-	-	-	-	-	-
10 - more	-	-	-	-	-	-
Casting	The number of processed casting surfaces					
The number of cores per casting	4		5		6	
	$l/d < 3$	$l/d > 3$	$l/d < 3$	$l/d > 3$	$l/d < 3$	$l/d > 3$
0 - 1	K2	K3	-	-	-	-
2 - 3	K2	K4	-	K5	-	-
4 - 5	K5	K6	K5	K6	K6	K7
6 - 7	K5	K7	K5	K6	K7	K7
8 - 9	K7	K7	K7	K7	K7	K7
10 - more	-	-	-	-	-	-

Group K1 - disks, belt wheels, flywheels, flanges, wheel cylinders, gaskets;
Group K2 - levers, forks, arms, pedals and similar;
Group K3 - exhaust manifolds, inlet manifolds;
Group K4 - crankcases, carters;
Group K5 - differential gear boxes, power lifts, drawbar frames;
Group K6 - engine blocks, cylinder heads;
Group K7 - clutch boxes, gearboxes;
Group K8 - special shapes…

The flow of metal

The rising of flow ability causes the relation between the mass of gross and net casting has been reduced. For nodular and lamellar iron castings flow abilities are practically equal. This is the reason why this parameter will not be taken into account.

The thermal conduction of molding sand λ

Thermal conduction of molding sand λ (W/mK) is λ the same for all castings when molding sand for all mould fields has been used, as this case. Further classification of λ is not necessary. The bigger λ caused the higher coefficient K_m and lower coefficient K_f.

The number of models on modeling plate

The number of models on the modeling plate depends on: the mass and dimensions of castings, the size of molding box at using, as the Table 3. shows and relations between length and diameter of casting (*l/d*). Regarding these parameters was made the classifications of numbers of models on model's plate, Table 4.

Technological process for cores producing

The mass of core mostly depends on casting cavity dimensions and applied method for core producing. The suitableness for each technological process of core production regarding configuration of casting and size of series has been presented, Table 5.

The mark CO_2 means the technological process with CO_2 is suitable for machine that makes cores while index *R* means hand made cores. The mark OP means the suitability of technological process for cores producing from coated sand. On the basis of mentioned parameters the synthesis of interaction between the materials in mould box in corelation with data from design draft were made.

Table 3. **The sizes of molding boxes at using for the researched sample**
Tablica 3. **Veličina kalupa u uporabi za uzorak na kojem se vrši istraživanje**

Mould field	Characteristics			
	Molding machine	The size of molding box	The mass of mold / kg	Average number of models on modelingplate / peces
I and II	FOROMAT 20	A = 400×400×150/200	- 10	m_5 = 6 - 8
III	FOROMAT 20-1A	B = 560×560×200/200	- 20	m_4 = 3 - 5
IV	FOROMAT 40	C = 800×600×250/300	- 90	m_3 = 2 - 3
V	Künkel-Wagner	D = 1300×1050×450/450	- 300	m_2 = 1 - 2
VI	manually	R = different	over 300	m_1 = 1

Table 4. **The classification of models number on the modeling plate**
Tablica 4. **Klasifikacija broja modela na modelarskoj ploči**

Casting		Size of molding box			
Mass group	l / d	A	B	C	D
g_1	$l/d < 3$	m_5	m_5	-	-
	$l/d > 3$	m_5	m_5	-	-
g_2	$l/d < 3$	m_4, m_5	m_5	m_4, m_5	-
	$l/d > 3$	m_4	m_4, m_5	-	-
g_3	$l/d < 3$	m_2, m_3	m_4	m_3, m_4	-
	$l/d > 3$	-	m_2	m_2, m_3	-
g_4	$l/d < 3$	-	m_2	m_2	m_3, m_4
	$l/d > 3$	-	m_1	m_2	m_3, m_4
g_5	$l/d < 3$	-	-	m_2	m_2
	$l/d > 3$	-	-	m_1	m_2
g_6	$l/d < 3$	-	-	-	m_2
	$l/d > 3$	-	-	-	m_2
g_7	$l/d < 3$	-	-	-	m_1
	$l/d > 3$	-	-	-	m_1

The determination of mass of gross metal insert

In relationships between the mass of gross metal insert and the mass of net casting the most influential parameters are: the mass of net casting, the complexity of casting configuration and the number of models on modeling plate. Generally, for the same mass group, when the shape of casting is complex the value of metal coefficient K_m has been raised while the number of models on modeling plate cause the of K_m's value go down. If the complexity of casting shape and number of models on modeling plate is constant the mass group of casting grows and the value of K_m will be withdrawn. The matrix of metal coefficient K_m and mass groups is presented in (12):

$$K_m = | K_m \; K_m \ldots K_m \ldots K_m |, \qquad (12)$$

where:

K_m - metal coefficient for mass group g_i, (i = 1 - 7),

$K_{m_k K_j}$ - the values of metal coefficient K_m for m_k - class of number of models on the modeling plate, complexity of casting configuration K_j and g_i - mass group of castings.

Accordingly to the Table 1.:

$$K_m^{g_i} = \begin{pmatrix} K_{m_1K_1}^{g_i} & K_{m_1K_2}^{g_i} & \cdots & K_{m_1K_j}^{g_i} & \cdots & K_{m_1K_n}^{g_i} \\ K_{m_2K_1}^{g_i} & K_{m_2K_2}^{g_i} & \cdots & K_{m_2K_j}^{g_i} & \cdots & K_{m_2K_n}^{g_i} \\ \vdots & \vdots & & \vdots & & \vdots \\ K_{m_kK_1}^{g_i} & K_{m_kK_2}^{g_i} & \cdots & K_{m_kK_j}^{g_i} & \cdots & K_{m_kK_n}^{g_i} \\ \vdots & \vdots & & \vdots & & \vdots \\ K_{m_nK_1}^{g_i} & K_{m_nK_2}^{g_i} & \cdots & K_{m_nK_j}^{g_i} & \cdots & K_{m_nK_n}^{g_i} \end{pmatrix} . \qquad (13)$$

Table 5. **The suitableness of each technological process for core producing regarding the configuration of casting and size of series**
Tablica 5. **Povoljnost pojedinog tehnološkog postupka za izradu jezgri ovisno o konfiguraciji odljevka i veličini serije**

Castings configuration	Annual production of castings					
	Till 500	501-1000	1001-5000	5001-10000	10001-20000	20001-50000
K1	CO_2R	CO_2R	CO_2R	CO_2	CO_2	O. P.
K2	CO_2R	CO_2R	CO_2R	CO_2	CO_2	O. P.
K3	CO_2R	CO_2R	CO_2R	CO_2	CO_2	CO_2
K4	CO_2R	CO_2R	CO_2R	CO_2	CO_2	CO_2
K5	CO_2	CO_2	CO_2R	O. P.	O. P.	O. P.
K6	-	-	O. P.	O. P.	O. P.	O. P.
K7	-	-	O. P.	O. P.	O. P.	O. P.
K8	-	-	-	-	-	O. P.

The determination of core mass

The size of core as a basic parameter which influences the core coefficient can be estimated by relation $K_j 1$ between core's volume and casting's volume.

The volume of core has been calculated by calculation of volumes of essential geometrical bodies which approximates the core's and casting's volumes:

$$K_j 1 = \frac{V_j}{V_0}, \qquad (14)$$

where:

K_j1 - the coefficient of relations between core's and casting's volumes.

For calculation of essential geometrical bodies volumes Simpson's and Gouldin's rules and other rules of geometry and planimetry were used:

$$K_j1 = \frac{\frac{G_j}{\rho_j}}{\frac{G_0}{\rho_m}},$$

where:

ρ_j = 1,4 kg/dm³, density of coated core sand and CO_2 core mixture,

ρ_m = 7,25 kg/dm³, average density of castings;

$$G_j = \frac{G_0 \cdot \rho_j}{\rho_m} K_j1; \tag{15}$$

$$\frac{\rho_j}{\rho_m} = \text{const.} = \frac{1,4}{7,25} = 0,193; \; G_j = G_0 \times 0,193 \times K_j1.$$

In (15) the estimated core volume is taken in consideration regarding coefficient K_j1. If "shell molding" process with coated sand is used for the reason to save the material the cavity in cores will be made, while CO_2 process not use the cavity for the saving of sand;

$$K_j1 \times K_j2 = \frac{V_{js}}{V_0}, \tag{16}$$

where:

V_{js} - real core's volume,

K_j2 - core filling up coefficient depending on: core mass and, the complexity of casting's shape and core production technological process of

$$G_j = G_0 \times 0,193 \times K_j1 \times K_j2. \text{ /kg} \tag{17}$$

In Table 6. are shown the coefficients K_j1 and K_j2 for:
x - estimated relation between core and casting = 0 - 1,
y1 … yn … y11 - the coefficient of core's fill up,
y1 = 1 for CO_2 process of core producing,
y2 - y11 = 0 - 1 for "shell molding" process for core producing.

The determination of mass of molding sand

In the expression (10) the previously accounted volumes of cores and gross metal insert are introduced in order to calculate the molding sand volume:

$$V_f = V_k - (V_n + V_j) \text{ /m}^3 \tag{18}$$

and from expression (11) the *mass of molding sand is determined:*

$$G_g = V_f \times \rho_f, \text{ /kg} \tag{19}$$

where:

ρ_f = 1,6 /(kg/dm³), density of pressed molding sand.

Table 6. **The determination of core coefficients K_j1 and K_j2 depending about influential factors**

Tablica 6. **Određivanje koeficijenata jezgri K_j1 i K_j2 u ovisnosti o utjecajnim elementima**

Castings		Cores			$\frac{\rho_j}{\rho_m}$
Complexity of castings shape	Mass / kg	K_j1	K_j2		
			CO_2	Shell molding	
K1	10	x	y_1	y_2	0,193
	40	x	y_1	y_3	0,193
K2	5	x	y_1	y_4	0,193
	10	x	y_1	y_5	0,193
K3	10	x	y_1	-	0,193
K4	100	x	y_1	-	0,193
	250	x	y_1	-	0,193
K5	50	x	y_1	y_6	0,193
	100	x	y_1	y_7	0,193
K6	100	x	-	y_8	0,193
	300	x	-	y_9	0,193
K7	150	x	-	y_{10}	0,193
	300	x	-	y_{11}	0,193
K8	-	-	-	-	-

THE CHECKING OF METHOD ON THE SAMPLE OF "TORPEDO" FOUNDRY

For the reason of quantifications of metal coefficient-K_m, core coefficient-K_j and mould coefficient-K_f, for given conditions of casting manufacture in "Torpedo" iron foundry, the representative sample of castings from serial production of "Torpedo" foundry were chosen and shown in [7], which is enclosed to the paper.

In table [7], in column 8 are put the quantified values of coefficient K_m from Table 7. where the quantifications are performed for castings from same configuration and same mass group.

In table [7], column 12 presents the accounted value of K_j1-coefficient. Calculated values for K_j2 are entered

Table 7. **The quantification of metal coefficient - K_m**
Tablica 7. **Kvantifikacija koeficijenata metala - K_m**

Casting			Complexity of casting shape						
No	Mass group	Num. of models on plate	K1	K2	K3	K4	K5	K6	K7
1	2	3	4	5	6	7	8	9	10
		m_1							
		m_2	1,7580	2,2	1,981				
	g_1	m_3	1,6955	2,025					
		m_4							
		m_5	1,7665	1,969					
1	g_1		1,73	2,40	1,90				
	g_2	m_1	1,5097		1,47				
		m_2	1,5172						
2	g_2		1,62	1,68	1,75	2,27			
	g_3	m_1	1,8846			1,944	1,852		
3	g_3		1,55	1,60	1,66	1,95	1,85		
	g_4	m_1	1,4850			1,635	1,688		
4	g_4		1,49	1,53	1,58	1,63	1,69	1,75	
	g_5	m_1				1,319	1,338		
5	g_5				1,30	1,31	1,32	1,33	1,34
	g_6	m_1					1,666	1,273	1,325
6	g_6						1,17	1,27	1,32
	g_7	m_1							1,308
7	g_7								1,30

in column 14, table [7]. The quantifications of this coefficient are performed due to influential parameters and presented in Table 8. and put in the column 15 of table [7].

Table 8. **Quantification of coefficients of core's fill up**
Tablica 8. **Kvantifikacija koeficijenata ispunjenosti jezgre**

Casting	Shape complexity	K1		K2		K3	K4	
	Mass till / kg	10	40	5	10	10	100	250
K_j2	CO_2 process	1	1	1	1	1	1	1
	Shell molding process	1	0,9	1	1	-	-	-
Casting	Shape complexity	K5		K6		K7		
	Mass till / kg	50	100	100	300	150	300	
K_j2	CO_2 process	1		-	-	-	-	
	Shell molding process	0,9	0,8	0,8	0,6	0,7	0,5	

The values for G_{pj} (calculated mass of cores) on the basis of coefficient-K_j2_{kv} values were calculated and entered in the column 16 of table [7].

CONCLUSION

The method for determination of gross metal insert mass and cores mass on basis of net mass of casting and design draft of casting were presented in this paper.

If the total amounts from Table 3.8. for real gross metal inserts and estimated ones are put in relation (using the quantified metal coefficient - K_{mkv} from Table 7.), where the frequency of each single casting is one, could be obtained:

$$\frac{G_{bs}}{G_{bsp}} = \frac{1932,86}{1996,61} = 0,97,$$

i.e. statistical average difference is 3,19 % < 5 % (normal dividing for interval $x \pm 2\sigma$). This result satisfies in spite of the fact that differences for single casting are up to 10 %. With listed is confirmed that all relevant essential influential parameters on relation between the mass of gross metal insert and mass of net casting are taken in consideration and their classification are made satisfactory.

If the total amounts from Table 3.8. for real and estimated mass of cores is put in relation (using: the quantified core coefficient K_j2_{kv} from Table 8., accounted core size coefficient-K_j1 and relation $\rho_j / \rho_m = 0,193$), where the frequency of each single casting is one, could be obtained:

$$\frac{G_{js}}{G_{jp}} = \frac{1205,03}{1198,06} = 1,0058,$$

i.e. statistical average difference is 0,58 %< 5 %. The result is satisfying. With listed is confirmed that all relevant essential influential parameters on relation between the mass of gross metal insert and mass of net casting are taken in consideration and their classification are made satisfactory.

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