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Assessment of the possibility of utilisation of used ceramic moulds originated from the investment casting technology

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Abstract

Review of wastes generated by investment casting technology and discussion on possibilities of disposal of the largest quantity waste from this technology - used ceramic mould is presented in the paper. Preliminary examinations of disintegration process of used ceramic mould conducted in various testing conditions were performed in the frame of presented research. Applied system of disintegration doesn't warrant obtained material to be suitable for reuse in production of ceramic moulds. Investigations of the inter-phase boundary: ceramic mould-casting were performed to examine environmental harmfulness of used ceramic moulds. Additionally ecologic assessment of spent moulds by means of it's elution in the aspect of qualifying possibilities of it's disposal were performed. Gained results qualify the waste from ceramic mould to storage in deposits for neutral wastes.

Keywords: investment casting, reclamation of used sand, leaching of used sand, management of waste.

1. Introduction

Main waste materials generated by precise casting houses – applying the lost foam method are: spent shell moulds, insoluble waxes, gypsum, plastic refractory sands (mixtures of binding agents and basic ceramic materials), soluble waxes and fibrous insulation materials.

The results of inventory of waste materials made in one of the precise casting houses in France are shown in Table 1 [1].

Quantitatively, the largest waste constitutes spent shell moulds. The most favourable procedure of their management, meeting the binding regulations of the environment protection, is the reclamation and reuse of the obtained material. This reclamation should allow to separate individual fractions, especially the most valuable micro-fraction. Various reclamation methods are used for this purpose: chemical, electro-hydro-mechanical, hydro-mechanical and mechanical in water medium. Reclamation trials without liquid agent (water) were also performed. This allowed to obtain very fine fractions of ceramic materials, however, without the removal of SiO_2 layer from grains, what is necessary for the possibility of using this material for sand moulds – for investment castings - preparation. Therefore further attempts will be directed towards more effective removal of SiO_2 layer to such a degree that individual fractions of ceramic material will be suitable for reusing in a process. In addition, investigations of phenomena occurring at the phase boundary: ceramic mould – casting, were performed and an ecological assessment of spent sand was done, which might be useful in the case of the necessity of its storage. The examined sands were from the ceramic casting moulds poured with CMSX-6 alloy (Cr-10%, Co-5%, Mo-3.0, Al-4.8%, Ti-4.7%, Ta-6.0%, Hf-0.1%, Ni – remaining amount).

Table 1. The results of inventory of main waste materials generated in French investment castings [1]

Waste group	Amount, Mg/year	Mass fraction, %	Procedure, Mg/year		
			Recovered	**Processed**	**Stored**
Insoluble waxes	1100	18	700	50	300
Gypsum	850	14	-	-	850
Spent shell moulds	3800	62	400	200	3200
Plastic refractory sands	312	5	-	6	306
Soluble waxes	80	1	-	13	10
Fibrous insulation materials	74	1	-	-	74

2. Examinations of a ceramic casting moulds disintegration

Examinations of disintegration of spent ceramic casting moulds were performed in order to determine possibilities and optimal ways of their crushing as well as to investigate how the obtained material could be reused.

2.1. Examination procedure

The crushing process of spent casting moulds consists of three main stages:

- Preliminary crushing in a jaw crusher to obtain broken up mould pieces. Dimensions of those elements are within a jaw crusher clearance, which means within 0.5-1 cm.
- Breaking up in a roller mixer. As a result of this operation the product, ready for further treatment, is obtained.
- Grain secondary disintegration. It is done in the experimental device described in papers [2, 3]. The speed of the rotating disintegrating element in this equipment can be changed within a broad range and a power consumption of a driving system can be measured.

A time-history of the performed tests together with times of processing and rotational speeds of disintegrating element are schematically presented in Figure 1.

2.2. Results of examinations

The results of the selected geometrical parameters, obtained by means of the sieve analysis after individual stages of the secondary disintegration of products, for three rotational speeds of the testing apparatus are presented in Table 2. On the basis of these data, one can notice that diameters of the crushed material are increased when the rotor rotational speed is increased, and that the duration of the process has no clear influence on the diameters. Geometrical parameters determined on the basis of the sieve analysis results indicate that the number of screenings on the finest sieve is essential for them. On the basis of detailed results of the performed sieve analysis it can be stated that the time increase of the disintegration process as well as the rotational speed increase of the testing equipment impact system does not correspond to any increase of the finest fraction amounts and even decreases them. Considering that this an illogical phenomena, from the point of view of the crushing and cracking mechanics, a microscopic analysis of the obtained products was performed. Photographs of surface morphology of the obtained disintegrated products are presented in Table 3.

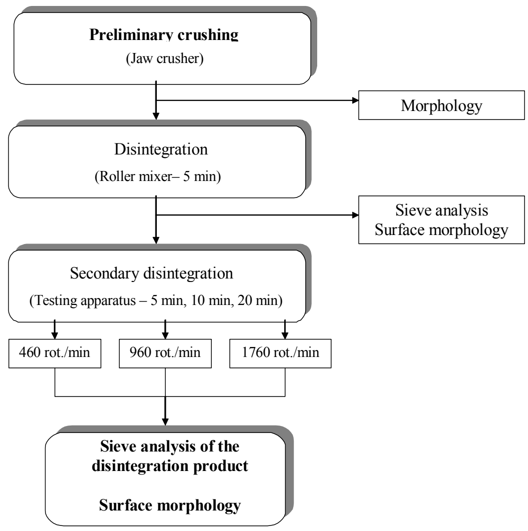


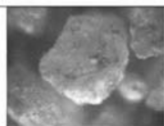
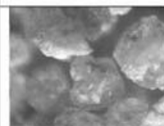
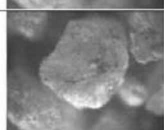
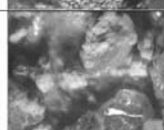
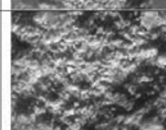
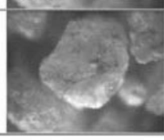
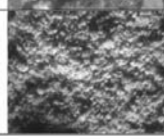
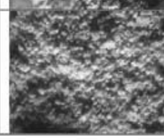
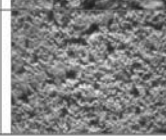
Fig. 1. Schematic presentation of crushing tests of spent ceramic casting moulds

Photographs of the surface morphology of the products of the secondary disintegration (at a magnification of 40 x) performed at three rotational speeds of the impact system of the testing equipment and duration of the process being successively 5, 10 and 20 minutes do not confirm the results obtained on the basis of the sieve analysis. It should be mentioned here, that samples analysed by means of the optical microscope were taken before performing the sieve analysis of the material. It means, that they were not subjected to the influence of the vibrating elements of the sieve analyser. Analysis of photographs allows to state, that the prolonged time of the disintegration process corresponds to the increased disintegration of the casting mould material. This phenomenon is observed for all three rotational speeds of the testing equipment, i.e. 460, 960 and 1760 rot./min. Such results are in accordance with the theory of material crushing and breaking, which states that the disintegration degree of material increases with the increase of work used for this disintegration.

Table 2. List of geometrical data of the secondary disintegration products determined on the basis of the sieve analysis

Rotational speed	Processing time	Main fraction	F_g	d_L	d_h	S_t	Ignition loss
Rot./min	min		%	mm	mm	cm^2/g	%
Material before the secondary disintegration	Material after disintegration in a roller mixer – 5min	0.80/0.40/0.63	84.90	0.168	0.122	118.92	0.28
460	5	0.80/0.40/0.32	55.94	0.175	0.135	106.75	-
	10	0.80/0.40/0.32	56.03	0.160	0.112	129.63	-
	20	0.80/0.40/0.32	55.95	0.172	0.121	119.50	0.38
960	5	0.40/0.80/0.63	53.49	0.179	0.144	100.21	-
	10	0.40/0.80/0.63	53.69	0.181	0.155	93.57	-
	20	0.40/0.80/0.63	50.42	0.168	0.141	102.49	0.19
1760	5	0.80/0.40/0.63	56.11	0.214	0.207	69.90	-
	10	0.40/0.63/0.80	52.52	0.213	0.193	75.04	-
	20	0.40/0.63/0.32	51.84	0.186	0.163	88.69	0.35

Table 3. Surface morphology of the secondary disintegration products, performed at various rotational speeds of the testing apparatus impact system. Magnification 40x

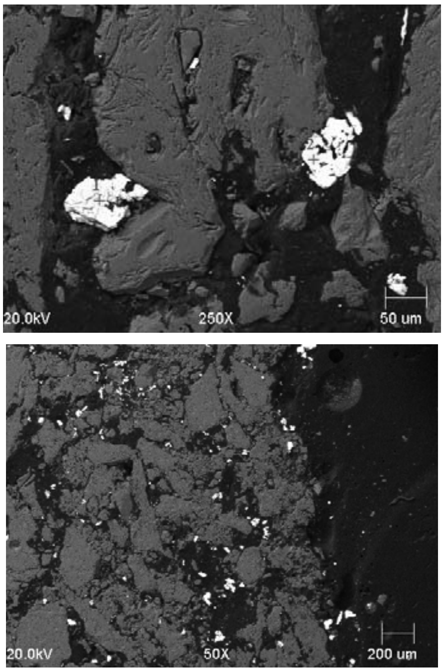
Rotational speed of the impact system of the testing equipment	Duration of the secondary disintegration process			
	Before the secondary disintegration	**5 minutes**	**10 minutes**	**20 minutes**
460 rot./min				
960 rot./min				
1760 rot./min				

3. Investigations of the inter-phase boundary: ceramic mould-casting

In order to investigate the inter-phase boundary the observations of three samples of the ceramic mould taken from various parts of the mould were made by means of the scanning microscope (JOEL ISM 5500 LM) and the X-ray Micro-Analyser. The Energy Dispersive X-ray Analysis (EDAX) was applied. The results of the local analysis are presented in Fig. 2-4.

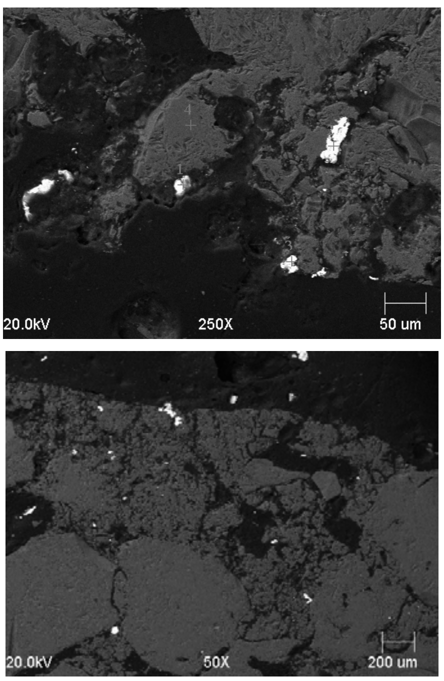
4. Ecologic assessment of spent sands

In order to perform this assessment investigations of elution of ceramic moulds poured previously by CMSX-6 alloy were carried on. The obtained results (presented in Table 4) indicate that spent ceramic moulds - used previously for investment casting technology - can be safely stored in storage yards for neutral wastes [4].



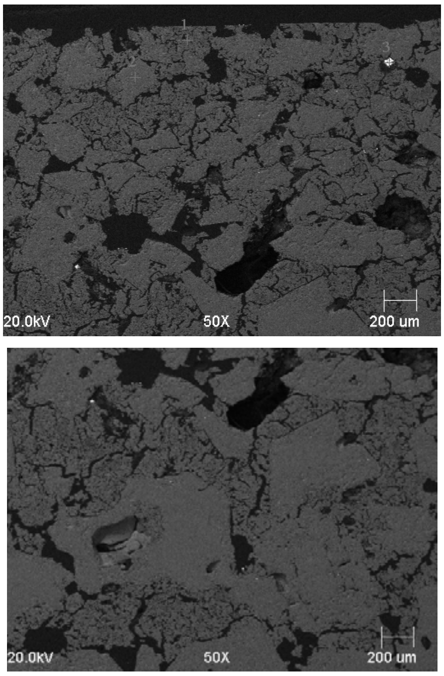
Element	Atomic %			% by weight		
	1	2	3	1	2	3
O	-	-	48.626	-	-	34.333
Al	0.507	0.066	49.815	0.230	0.030	59.315
Ti	0.178	0.183	0.102	0.143	0.150	0.214
Cr	0.203	0.140	0.000	0.177	0.124	0.000
Mn	0.000	0.101	0.432	0.000	0.095	1.048
Fe	98.919	96.869	0.171	89.924	92.089	0.420
Co	0.000	0.000	0.272	0.000	0.000	0.707
Ni	0.000	0.210	0.000	0.000	0.210	0.000
Mo	0.135	0.193	0.159	0.218	0.314	0.674
Ce	0.042	0.024	0.034	0.100	0.058	0.207
Hf	0.706	0.293	0.391	2.115	0.891	3.081
Ta	0.964	0.207	0.000	2.928	0.639	0.000
W	1.031	0.732	0.000	3.181	2.292	0.000
Re	0.315	0.981	0.000	0.984	3.109	0.000

Fig. 2. Sample No 1 ceramic mould (inner light part): magnification 50x (left image); magnification 250x (right image). Topographic electron image with a marked zone of X-ray analysis



Element	Atomic %				% by weight			
	1	2	3	4	1	2	3	4
O	-	-	0.000	46.169	-	-	0.000	32.884
Al	0.977	0.980	2.816	52.533	0.395	0.448	1.227	63.100
Si	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ti	0.214	0.173	3.913	0.000	0.154	0.140	3.024	0.000
Cr	0.055	0.000	36.423	0.000	0.043	0.000	30.576	0.000
Mn	0.074	0.031	1.155	0.258	0.061	0.029	1.024	0.632
Fe	0.136	95.807	0,477	0.357	0.114	90.539	0.430	0.886
Co	0.285	0.000	6.296	0.434	0.252	0.000	5.991	1.138
Ni	0.275	0.000	34.817	0.000	0.242	0.000	32.994	0.000
Cu	94.851	0.132	0.073	0.000	90.420	0.142	0.075	0.000
Mo	0.151	0.125	11.975	0.098	0.217	0.203	18.549	0.418
Ce	0.123	0.060	0.000	0.151	0.259	0.141	0.000	0.942
Hf	0.000	0.583	0.458	0.000	0.000	1.760	1.321	0.000
Ta	1.113	0.246	0.000	0.000	3.022	0.754	0.000	0.000
W	1.504	0.658	0.361	0.000	4.148	2.048	1.072	0.000
Re	0.241	1.205	1.236	0.000	0.673	3.797	3.717	0.000

Fig. 3. Sample No 2 ceramic mould (inner grey part) from left: magnification 50x; magnification 250x. Topographic electron image with the marked zone of X-ray analysis



Element	Atomic %			% by weight		
	1	2	3	1	2	3
O	53.951	51.705	0.000	37.671	38.510	0.000
Al	36.435	47.732	1.001	42.903	59.953	0.428
Ti	7.391	0.000	0.000	9.059	0.000	0.000
Cr	0.098	0.134	0.000	0.205	0.298	0.000
Mn	0.229	0.332	0.460	0.519	0.804	0.379
Fe	0.282	0.000	0.208	0.677	0.000	0.181
Co	0.191	0.000	91.077	0.466	0.000	80.586
Ni	0.273	0.000	0.000	0.703	0.000	0.000
Mo	0.198	0.000	0.879	0.506	0.000	0.817
Ce	0.062	0.097	0.552	0.262	0.434	0.838
Hf	0.382	0.000	1.842	2.975	0.000	5.209
Ta	0.227	0.000	1.751	1.795	0.000	5.019
W	0.175	0.000	1.075	1.402	0.000	3.131
Re	0.105	0.000	1.156	0.857	0.000	3.411

Fig. 4. Sample No 3 ceramic mould (inner pink part) magnification 50x. Topographic electron image with the marked zone of X-ray analysis

Table 4. Results of leaching out of spent ceramic moulds poured by CMSX-6 alloy

Sample marking	**Moulding sand – water extract at the rate to solid phase 10 l/kg mg/l**	**Moulding sand – water extract at the rate to solid phase 10 l/kg mg/kg, d.s.**	**Allowable limiting values of elution - for neutral wastes storage yard, mg/kg, d.s.**
Arsenic	<0.005	<0.05	0.5
Barium	0.001	0.01	20
Cadmium	<0.0005	<0.005	0.04
Total chromium	0.002	0.02	0.5
Copper	0.006	0.06	2
Mercury	<0.0005	<0.005	0.01
Molybdenum	<0.01	<0.1	0.5
Nickel	0.006	0.06	0.4
Lead	<0.005	<0.05	0.5
Antimony	<0.005	<0.05	0.06
Selenium	<0.01	<0.1	0.1
Zinc	<0,007	<0.07	4
Chlorides	0.42	4.2	800
Fluorides	0.052	0.52	10
Sulphates	1.76	17.6	1000
Phenol indicator	0.005	0.05	1
DOC	3.93	39.3	500
TDS	32	320	4000
Σ WWA	<0.05 μg/l	<0.5 μg/kg d. s.	1000 μg/kg d. s.
Naphthalene	<0.005 μg/l	<0.05 μg/kg d. s.	
Anthracene	<0.005 μg/l	<0.05 μg/kg d. s.	
Fluoranthene	<0.005 μg/l	<0.05 μg/kg d. s.	
Benzo(b)fluoranthene	<0.005 μg/l	<0.05 μg/kg d. s.	
Benzo(k)fluoranthene	<0.005 μg/l	<0.05 μg/kg d. s.	
Benzo(a)piren	<0.005 μg/l	<0.05 μg/kg d. s.	
Dibenzo(a,h)anthracene	<0.005 μg/l	<0.05 μg/kg d. s.	
Indene(1,2,3-cd)piren	<0.010 μg/l	<0.1 μg/kg d. s.	
Benzo(ghi)perylene	<0.005 μg/l	<0.05 μg/kg d. s.	
pH value	6.7	-	
ChZT-Cr	10.3	-	
Nitrate nitrogen	0.026	0.26	
Chromium +6	<0.01	0.1	
Free cyanides	<0.003	0.03	

5. Conclusions

The following conclusion can be drawn on the bases of the performed examinations:

1. Increased intensity of impact influence causes an increased degree of disintegration of spent casting moulds material. This was exhibited by the examination of grain surface morphology, however not confirmed by the sieve analysis. Several reasons - due to which - the sieve analysis did not show an actual disintegration of the analysed material were determined. The main ones are: a phenomenon of agglomeration of small grains occurring due to an influence of vibrating sieve as well as an electrostatic adhesion of dusty fractions to larger fractions.
2. Accurate analysis of microscopic images, performed within the hereby paper, allows to mention that in all analysed fractions of material being disintegrated the fine 'dusty' fractions can be seen on larger grain surfaces. This phenomenon is especially visible on fractions: 0.16 mm, 0.100 mm and 0.071 mm. However, on the basis of the presented examinations, it is not possible to determine the quantitative participation of dusty fractions which became agglomerated and in such way influenced the results of the sieve analysis.
3. The presence of zones containing metal phases (elements originated mainly from the cast alloy: Co, Ta, W, Ni, Mo) and Al_2O_3 phase was noticed at the interface boundary: ceramic mould-casting.
4. Spent ceramic moulds can be safely stored in the storage yards for neutral wastes.

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References

1. Duquet B.: Caractėrisation et ėtude du devenir des dechets de fonderie de prėcision. Fonderie – Fondeur D'Aujourd'hui, 2001, NR 203, 22 – 30.
2. Dańko J., Dańko R, Łucarz M.: Procesy i urządzenia do regeneracji osnowy zużytych mas odlewniczych. Wydawnictwo Naukowe AKAPIT, Kraków 2007.
3. Dańko R.: Podstawy teoretyczne i technologiczne doboru optymalnych sposobów regeneracji suchej zużytych mas odlewniczych. Praca doktorska. AGH Kraków, 2006.
4. Holtzer M.: Gospodarka odpadami i produktami ubocznymi w odlewniach. Wydawnictwa Naukowo-Dydaktyczne AGH, Kraków 2001.