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Synthesis and Characterization of Cordierite from Kaolin and Talc for Casting Application

Standard raw materials, kaolin and talc, were used in synthesis of cordierite ceramics. Cordierite mass corresponded to $2MgO\text{-}2Al_2O_3\text{-}5SiO_2$ *composition. Synthetized cordierite was used as a refractory filler in the ceramic layer for evaporative polystyrene patterns in the new casting technology, Lost Foam Process. Cordierite characterization was carried out by means of x-ray structure analysis. Powder particles morphology was analyzed by the scanning electronic microscope. The characteristic temperatures for carrying out solid state reactions in the three-component system of* $MgO\text{-}2Al_2O_3\text{-}SiO_2$ *were determined differentially by thermal analysis in the range from ambient temperature to* 1100 ^oC. *Obtained ceramic linings were applied to polystyrene pattern of* 20 kg/m^3 *density, polystyrene grain size of* 1.5 mm, *followed by "full mould" casting. For the purpose of realistic evaluation of possible cordierite application in the production of evaporative pattern ceramic lining, concurrent analyses with talc based lining were carried out. Cordierite has wide application in electrothermics, electronics and engineering industry, however, it has not been used in casting yet.*

Keywords: *Cordierite, Talc, Lost Foam Casting Process.*

INTRODUCTION

Technological properties of cordierite ceramics are direct function of the polystyrene material structure. The wide use of cordierite ceramics is, above all, the result of its properties, such as, low heat expansion coefficient, refractoriness and its outstanding resistance to heat impact. However, a very narrow interval of cordierite ceramics sintering practically disables obtaining dense materials without special equipment and additives, which, on the other part, do not deteriorate desired properties, which makes one of the main problems encountered in cordierite ceramics production. Standard cordierite masses based on kaolin, talc, technical grade alumina have a narrow sintering interval, 10-20^o C, which makes the products highly sensitive to baking, because of deformation, as well as deteriorated properties. Cordierite mass sintering is observed at the temperatures close to cordierite melting temperature. At lower temperatures, cordierite synthesis and sintering do not occur practically, while the increase of temperature results in significant glazing phase, which calls for the increase of heat expansion coefficient and the decrease of product thermal stability [1-7].

Cordierite, as $2MgO\text{-}2Al_2O_3\text{-}5SiO_2$ mineral, occurs in very small quantities. Cordierite synthesis is possible directly from oxide. However, in industrial production of cordierite ceramics, natural materials are used, such as, talc, high quality refractory clays, calcinated alumina and electro melted corundum, magnesium carbonate, quartz, phorsterite (8-10).

CERAMIC LININGS FOR THE LOST FOAM PROCESS

The Lost Foam process has been developing intensively for the last three decades in the renown Swedish foundries for the production of complex parts to be used in car and aircraft industries. For successful production of castings by this method, it is necessary to establish balance in the system: evaporative pattern-ceramic lining-liquid metal-sand. It is also necessary to determine correlation of the relevant technological process parameters-polystyrene pattern density, ceramic pattern layer kind and thickness, casting temperature, pervious ness of moulding sand with obtained castings quality [11-15].

There are several kinds of evaporative pattern linings with different thermo physical characteristics, which are specially designed to meet a number of requirements of the Lost Foam casting process (Figure 1) [16].

According to the data, the world known companies engaged in ceramic linings production and application invest considerable resources in systematic research on various ceramic materials for refractory fillers, selection of suitable materials for additives which keep suspension stable, and materials for binding system.

One of the main tasks of ceramic linings is to enable removal of desintegration products and evaporation of polystyrene patterns, which is carried out in the pattern contact with liquid metal during pouring. They also have to prevent metal penetration into the mould.

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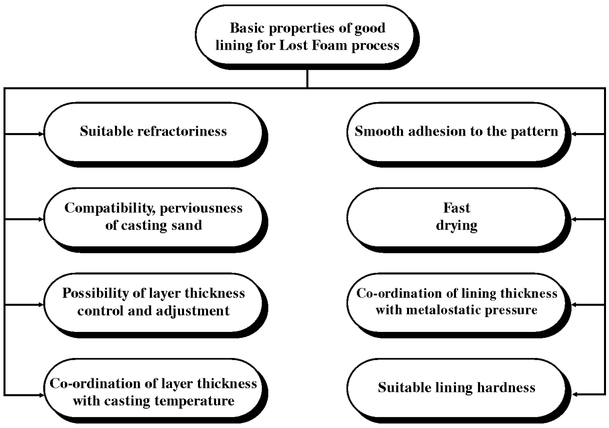

Figure 1. Basic ceramic lining properties in the Lost Foam process.

Selection of ceramic lining is carried out in accordance with the types of metal and alloy to be casted, i.e. casting temperature. Higher casting temperatures enable faster process of pattern desintegration and evaporation, as well as more gas accumulation which has to be removed from the mould. This calls for thicker lining layers and higher lining perviousness. Acccording to the researches, lining thickness is in the range of 0.1-0.7 mm. When thicker linings are used, their imperviousness decrease, which can cause a series of faults in obtained castings [17,18].

Lining layer thickness must be uniform on the entire pattern surface. The lining must adhere well to the pattern surface, and it also has to be removed easily from the casting surface. Some linings have strong insulating property. It is desirable with a number of alloys, e.g. Al- alloys, as the linings reduce fast heat transmission from the liquid metal into the sand surrounding the pattern. Polymer desintegration is an endothermic process which causes sub-cooling in the metal front. This can result in porous and rough surface of castings. As the main function of the lining is to produce casting quality surface, ceramic lining for Al-alloys has to insulate heat from the front of metal to be poured into the "full mould" [19].

Having known the above cordierite ceramics characteristics and quality requirements for the ceramic linings used in the Lost Foam process, the idea of investigating its possible application as a refractory filler, was formed. Special attention during the work was paid to studying the process of cordierite base formation, in order to determine parameters needed for producing ceramic linings with previously requested properties [20].

EXPERIMENT

Cordierite used for ceramic lining was produced by high temperature reaction in solid state, in which kaolin and talc were used for synthesis (Table 1).

Table 1. Composition of cordierite mass.

Desingnation	Component type, %	
	kaolin	talk
C_n	79	21

In Table 2. the composition of starting components mixture for cordierite production is shown.

Table 2. Chemical composition starting components mixture for cordierite production

Component	Colour	Ign. loss	Fe_2O_3	Al_2O_3
Kaolin (SEDLES-Check Republic)	beige	8,14	1,34	28,83
Talc (Italy)	white	5,30	0,28	1,18

Component	Colour	SiO_2	CaO	MgO
Kaolin (SEDLES-Check Republic)	beige	53,0	0,50	0,00
Talc (Italy)	white	60,15	1,50	31,40

Starting components were ground 0.1mm grain size, homogenzed, pressed under 1 MPa pressure, then sintered in a laboratory oven. The obtained cordierite samples were used for ceramic linings in the Lost Foam process.

The obtained cordierite powders were x-ray structure analysed on Philips type PW 1710 difractometer, where radiation from copper anticathode and graphite monochromator was used. Work pressure was 40 kV, power rate I=30 mA, and the sample was tested in the range of 20.5 –85 ^{o}.

Morphology of the obtained cordierite powder was analysed by the scanning electronic microscope (JEOL-T-20) with 750 x 2000 magnification. The samples were ultrasound deaglomerated in etalon for 10 minutes, then gold spattered.

In order to analyse the characteristics of temperatures at which reactions were carried out in three-component solid state of MgO-Al_2O_3-SiO_2, a differencial-thermal analysis was done on SHIMADZU DTA-50 device at 10^{o}C heating rate and in the range from ambient temperature to 1100^{o}C.

Composition of the cordierite based lining:

- refractory powder, cordierite of 40 μm grain size, 91%,
- binder: bentonite 1-2 %, bindal H 0.5 – 1 %, clay from cordierite,
- agents for keeping suspension stability: $Na_3P_3O_{10}$, 1.3 %, carboxymethil cellulose 0.5-1 %,
- solvent: water.

Parameters of pattern polymer lining, 20kg/m^3 density:

- suspension density: 2 g/cm^3,
- temperature: 22 ^{o}C,
- slow suspension mixing during lining application to the pattern, at 10min. rate,
- lining technique: immersion, pouring, brush application,
- drying: first layer: 1.5 h, final layers: 24 h in the air,
- layer thickness after drying: 0.15 mm.

When applying pattern suspension, adhesion to the pattern surface was evaluated and the dried lining was tested for bubbles, scaling, abrasion resistance and wiping off.

In order to determine refractory filler distribution in the lining suspension, specially prepared materials were observed on the polarizing microscope.

After drying, the lined patterns were placed into steel moulding boxes, and covered with free quartz sand of

0,26 grain size. Casting was carried out after moulding. The alloy AlSi10Mg was used for testing at casting temperature 730 °C. Preparation of the liquid metal was done by rafination of salt, RAFALIT S, supplied by TERMIT, Domzale, 0.1 % of the casting mass, followed by degasification with 0.3 % briquetted C_2Cl_6 (Termit, Domzale) and modification with 0.05% natrium. After hardening and cooling, the castings were shaken out of moulds and tested.

For concurrent analyses, aimed at evaluation of the cordierite ceramics based lining, the castings produced by the Lost Foam process, with T-talc ceramic lining, were used.

Composition of talc based lining:

- refractory filler, talc, grain size 40 µm, 89%,
- binder: bentonite 3.3 mass °/o, bindal H 8%,
- suspension stability keeping agent: dextrine 0.5-1 mass %, lucel 0.5-1 mass %,
- solvent: water up to the required density of 2g/cm^3

RESULTS AND DISCUSSION

In Table 3, the cordierite and talc composition, used for production of ceramic lining by the Lost Foam process, is shown.

Table 3. Composition of cordierite and talc as refractory filler.

Item	Chemical composition (%)				
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Cordierite (C)	45,52	28,10	1,23	3,70	15,90
Talc (T)	62,20	3,11	1,25	1,07	4,10

The test results of C and T suspension preparations on the polarizing microscope are shown in Fig. 2 and Fig. 3.

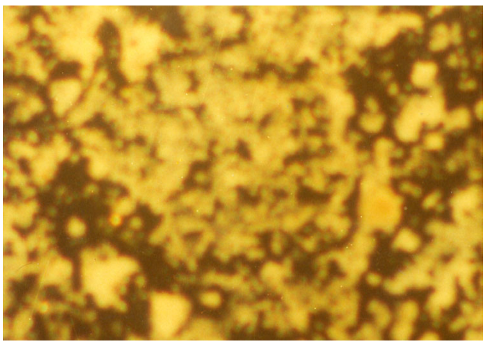

Figure 2. Microphotograph of C suspension.

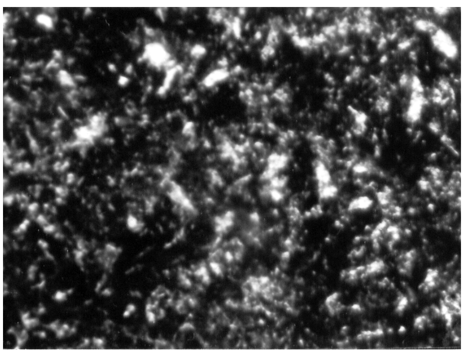

Figure 3. Microphotograph of T suspension.

In the suspension of the ceramic lining C, the presence of tiny irregular cordierite scales, linked with binder, and uniformely distributed in solvent, is shown. Obsering the prepared lining suspensionson talc basis, tiny, irregular scales of talc and chlorite, whose dimensions were rarely exceeding 20 µm, were noticed. The scales were rather homogenously distributed in the lining mass and linked by hexametaphosphate.

Homogeneity of the refractory filler distribution in the lining suspension depends on suspension preparation in the course of lining application. It is necessary to provide continuous slow mixing, keeping defined density (2g/cm^3) and temperature (20-22°). The obtained linings, C and T, did not crack, not scale or wipe off. After casting, and shaking casting out of the mould, the lining was easily removed from the casing surface.

In Fig. 4 and Fig. 5., roendgenograms of samples C and T are shown.

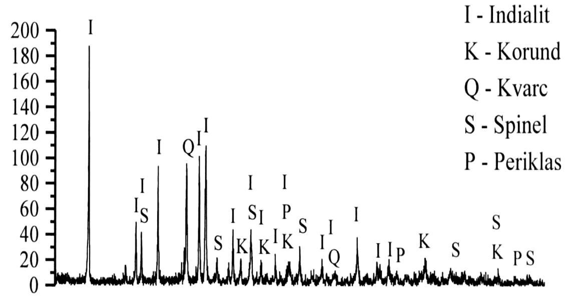

Figure 4. Roentgenogram of lining C suspension.

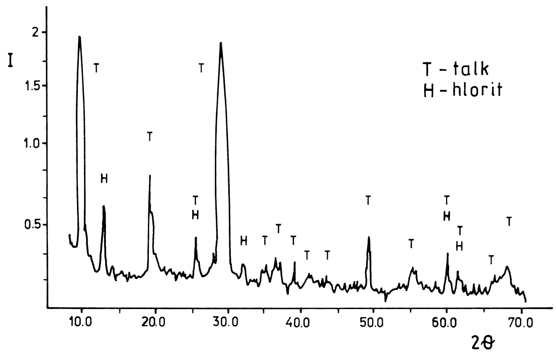

Figure 5. Roentgenogram of lining T suspension.

In Fig. 4, dominant presence of cordierite, as well as spinel and quartz, is shown. In Fig. 5, dominant presence of talc can be identified.

In Fig. 6, DTA of the sample curve, with chracteristic temperatures, is shown.

Endothermic effect is correspons to phase transformation α - tridimite $\rightarrow$ α - quartz, while the exothermic effect is corresponds to the reaction between MgO and SiO_2, whereby magnesium metasilicate occurs.

Analysis o microphotographs, obtained by electronic microscopy, shows that sample C contains the mixture of big and small particles, and fine pores. Surface morphology changes are not visible, however, with higher magnification, porous appearance is visible on the sample surface (Fig. 7). Talc particles are of uniform size and similar morphology (Fig. 8). From the asspect of ceramic powders used as refractory fillers, grain size difference is favorable. Particles of different grain size contribute to better uniform, continuos lining on the pattern, due to better correspondence between the particles.

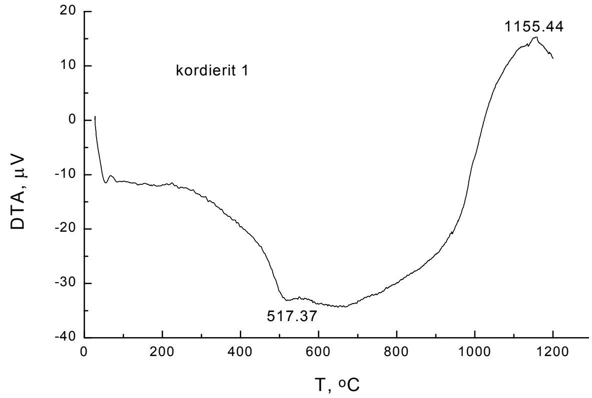

Figure 6. DTA curve of sample C.

Figure 7. SEM photograph of sample C.

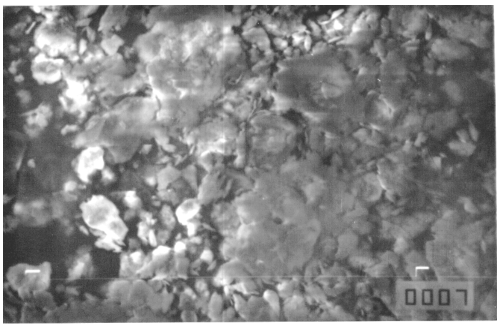

Figure 8. SEM photograph of sample T.

After casting AlSi10Mg alloy, and shaking the castings out of moulds, it was found that the castings were accurate copies of the pattern. It indicates that, by choosing the casting temperature of 720^{o}C, the linings based on cordierite and talc, with 0.15 mm layer thickness, provided balanced conditions of the system: evaporative pattern-ceramic lining-liquid metal-sand. There were neither piercing of ceramic lining, metal penetration into sand, nor sand sintering. Casting surfaces were bright and clean so that no machining was necessary.

Testing structural and mechanical characteristics of casting series C and T shows that there are no substantial differences in results obtained, except for moderate increase of grain size in casting C structure, which occurred due to greater insulating effect of lining C, in relation to lining T (Figures 9 and10).

The structure consists of solid solution primary α crystals and multicomponent eutectic in which intermetallic phases, based on Al, Fe, Mn, Si, are extracted. Structural and mechanical properties are within the limits anticipated for this type of alloys. Further research in this field should be directed to studying modification process in order to moderate the insulating effect of ceramic lining, which causes grain growth in the structure.

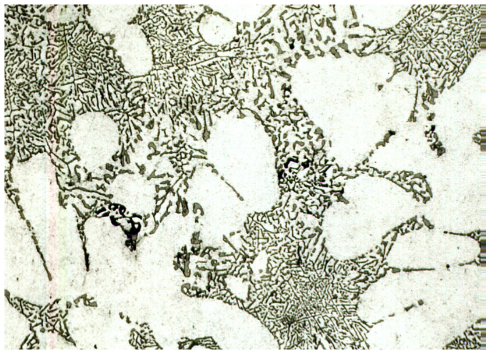

Figure 9. Microstructure of casting series C

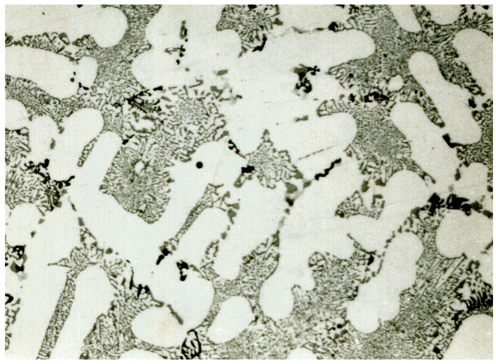

Figure 10. Microstructure of casting series T

CONCLUSION

The application of cordierite as a refractory filler in producing ceramic linings for evaporative patterns, in the Lost Foam process, synthetized from standard raw materials, talc and kaolin, has shown positive effects. Cordierite can be sintered easily, raw materials for its synthesis are available and inexpensive. The characteristic of cordierite to show low coefficient of thermal expansion makes it interesting for study and application in ceramic linings because of reduced risk from lining cracking at temperature changes during the process of liquid metal pouring. As cordierite also has high refractory properties, its application should be extended to casting alloys with melting temperatures below 1100^{o}C. Development of cordierite based ceramic lining can contribute to development of the Lost Foam casting process, as well as to its application in castings from a larger number of metals and alloys.

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СИНТЕЗА И КАРАКТЕРИЗАЦИЈА КОРДИЈЕРИТА ИЗ КАОЛИНА И ТАЛКА ЗА ПРИМЕНУ У ЛИВАРСТВУ

Љ. Трумбуловић, З. Аћимовић, С. Панић, Љ. Андрић

Стандардни материјали, каолин и талк, су коришћени у синтези кордијерита. Кордијерит у великој мери одговара структури $2MgO\text{-}2Al_2O_3\text{-}5SiO_2$. Синтетизовани кордијерит је коришћен као ватростални прах у керамичкој облози за испарљиве моделе од полистирена у новој технологији ливења, метода испарљивих модела. Карактеризација кордијерита је извршена употребом методе испитивања структуре помоћу *x*-зрака. Морфологија прашкастих честица је анализирана скенирајућом електронском микроскопијом. Карактеристичне температуре за извођење реакција у чврстом стању у трокомпонентним системима $MgO\text{-}2Al_2O_3\text{-}5SiO_2$ су одређене диференцијално термијском анализом у интервалу од собне до 1100°C. Добијена керамичка облога је примењена на модел од полистирена густине 20 кг/м^3, величина зрана полистирена је 1.5 мм и примењена код ливења у ″пун калуп″. Ради реалне процене могуће примене кордијерита у производњи облога за испарљиве моделе, извршена је упоредна анализа са талком. Кордијерит има широку примену у електротермији, електроници и индустријском инжењерству, међутим, још увек није употребљаван у ливарству.