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Evaluation of High-temperature Physico-chemical InteractionsBetween the H282Alloy Melt and Ceramic Material of the Crucible

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Abstract

Nickel alloys belong to the group of most resistant materials when used under the extreme operating conditions, including chemically aggressive environment, high temperature, and high loads applied over a long period of time. Although in the global technology market one can find several standard cast nickel alloys, the vast majority of components operating in machines and equipment are made from alloys processed by the costly metalworking operations. Analysis of the available literature and own studies have shown that the use of casting technology in the manufacture of components from nickel alloys poses a lot of difficulty. This is due to the adverse technological properties of these alloys, like poor fluidity, high casting shrinkage, and above all, high reactivity of liquid metal with the atmospheric air over the bath and with the ceramic material of both the crucible and foundry mold. The scale of these problems increases with the expected growth of performance properties which these alloys should offer to the user.

This articlepresents the results ofstudies of physico-chemicalinteractions that occur between theH282alloy melt and selectedrefractoryceramic materialscommonly usedin foundry. Own methodologyforconducting micro-melts on a laboratory scale was elaborated and discussed. The resultsobtained have revealed thatthe alumina-based ceramicsexhibits greaterreactivityin contactwith the H282 alloy meltthanthe materials based onzirconium compounds.Intheconductedexperiments, theceramicmaterials based on zirconiumsilicate haveproved to bea much better choice than the zirconia-silica mixture.Regardless of the typeof the ceramic materials used,the time andtemperature of theircontact with thenickel alloy melt should always be limited toan absolutely necessaryminimum required by the technological regime.

Keywords: **N**ickel alloys, Superalloys, Melting, Reactivity, Metal/ceramic reaction, Refractory materials

1. Introduction

Nickel alloysform a groupof materials thatin liquid statestronglyreact withthe ceramicsof which both the induction crucible in a melting furnaceandcasting mold are made.This applies in particulartosuperalloys, including H282, which containa significant amount ofreactivealloying elementssuch as aluminumand titanium.In H282the contentofAlexceeds 1wt%andthat of Ti–2wt%[1-3]. These elementsat high temperatureare very intensivelycombined with oxygen.

Therefore,during melting, it is very importantto reduce to minimum the amount of oxygen dissolvedin liquidalloy[4,5].

H282 is an alloy of the latest generation and is regarded as a strategic material. For this reason, the available reference sources lack any reliable data on the thermo-physical and technological aspects of melting and solidification of this alloy in the high range of temperature values, necessary for proper development of the casting process and heat treatment of this alloy.

One of the manyproblems faced during meltingof these alloysis the selection ofproperrefractory materials.This issue has beenthe subject of numerous studies undertaken by various research centers dealing withthe melting and castingof nickel alloys.A numberof research worksin this particular field of knowledgehave beencarried outalso by the Foundry Research Institute in Cracow[6-8], focusing attention onthe development ofceramic materialscharacterized by a lowreactivity withliquidnickel alloys.

2. Test methodology

To examine themelt/ceramic interaction, tests werecarried out which consisted inmeltingthe H282 alloyin a vacuummedium frequencyinduction furnacein a speciallydesigned“insert”placed in the furnaceheating inductor. Due to the use of this elementit was possible to simultaneouslymeltunder the same conditionsseveral small batches of metal(up to 2kg), placed inspecially designed small ceramic crucibles (“inserts”). Tests were performedby melting the H282alloyin 3crucibles made of differentceramic materials, i.e.alundum-crucibleno. 1,zirconia+silica-crucible no. 2,zirconium silicate-crucible no. 3.

Figure1showsthe test crucibles filledwith a charge(H282 alloy),the location ofcontrol thermocouplesand the process ofmetal melting.

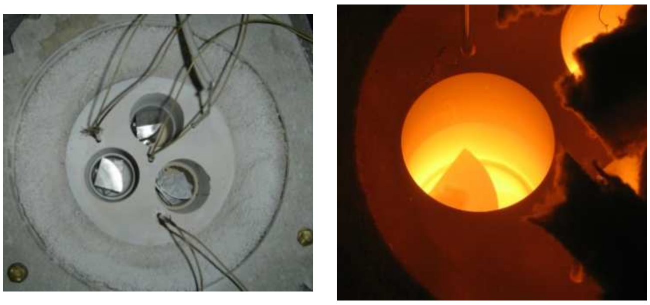


Fig. 1. Photographsshowing thelaboratory meltingsystem for nickel alloysbased on a KOPPvacuum inductionfurnace: at the top- loadingof charge, at the bottom-melting in one of the threesmall crucibles

The metal after meltingwas superheatedto a temperature of1450°C. At this temperature,it was held for30 minutesandthen thepower toinductorwas switched off,allowing theingotsto cool down together with furnaceto ambient temperature.

3. Results

Tests showeddifferent degree ofthe crucible damage (Figure 2) and of the metal/ceramicreaction productspenetration into the ingotsurface layer(Figure3).

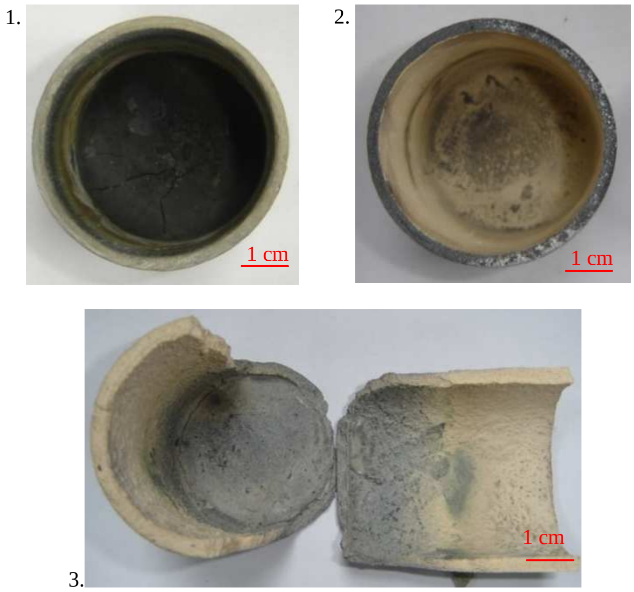


Fig. 2. The appearance of theinnersurface of respective cruciblesaftermelting the H282 alloy crucible no. 1 – alundum,crucible no. 2 - zirconia + silica,crucible no. 3 –zirconium silicate

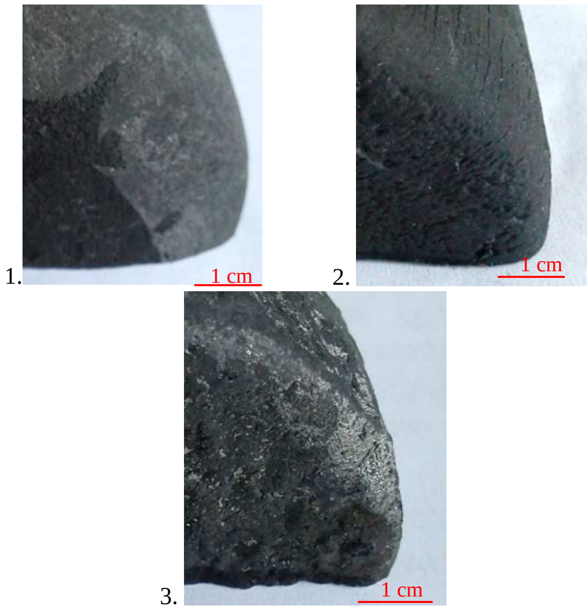


Fig. 3. The appearance of the surface of ingots made from the H282 alloy melted in different crucibles crucible no. 1 – alundum, crucible no. 2 - zirconia + silica crucible no. 3 – zirconium silicate

The ingotscastin individual crucibleswerenext subjected to metallographic examinations. Usingan opticalmicroscope,the outer layers ofmetaldirectly contacting the ceramicmaterial were examined. The microstructureof these layersis shownin Figure 4.The observations of microstructure showedthat the metal/ceramicreaction was progressing mostintensivelyincrucible no.1 (large pitspenetratingfrom the surfaceinto theingot interior). The metal from the other twocruciblesbehavedin a similar manner. The only difference was thatthe metal from crucible no. 2 contained underthe outer ingot layernumerous coloniesof titaniumnitrideprecipitates.

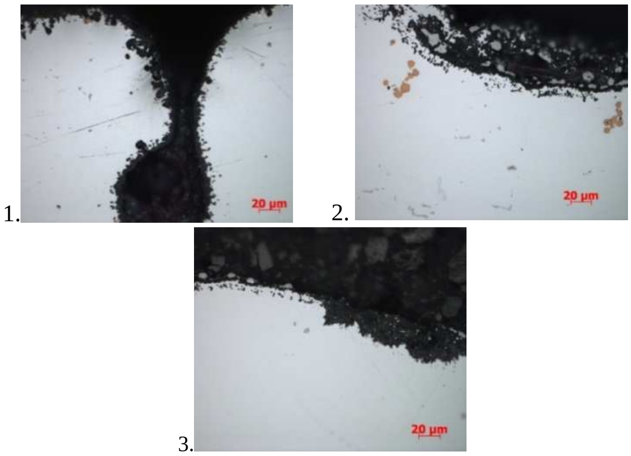
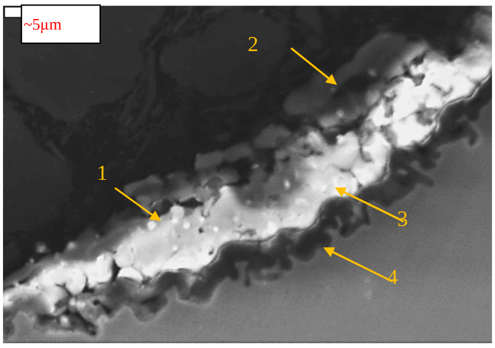


Fig. 4. Microstructure in the outer layer of ingots crucible no. 1 – alundum, crucible no. 2 - zirconia + silica, crucible no. 3 – zirconium silicate

The aim of further metallographicstudies was to carry outa chemical analysisin the edgelayerof the castingots.Based on the results obtained,an attempt was made to identify thephasespresent in this layer. The study was conductedusingan EDS LINK ISIS X-raymicroanalyzermade by OxfordInstruments.

In the case ofalundumcrucible (crucible no.1), the edge layerof the ingotwas found to be enrichedintitanium,aluminumandoxygen, which means that oxides of thosemetals were present there.Figure 5shows this effect.



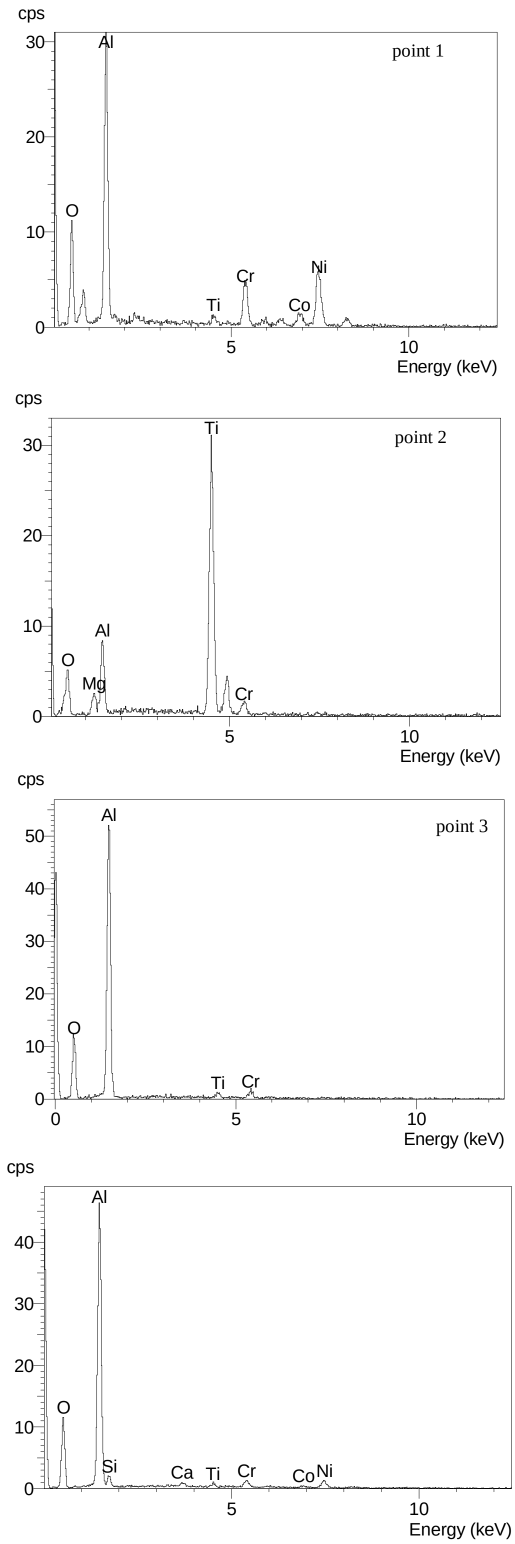
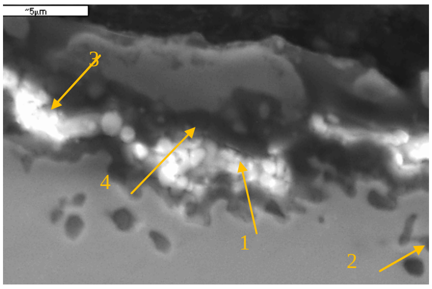
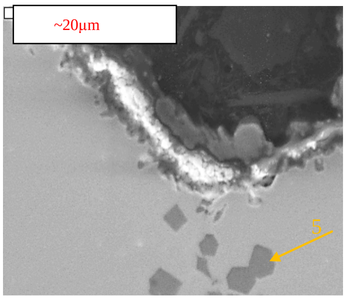
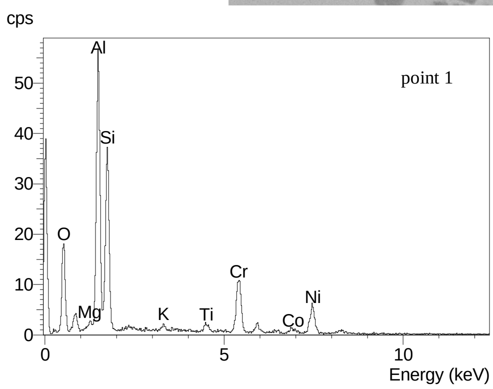


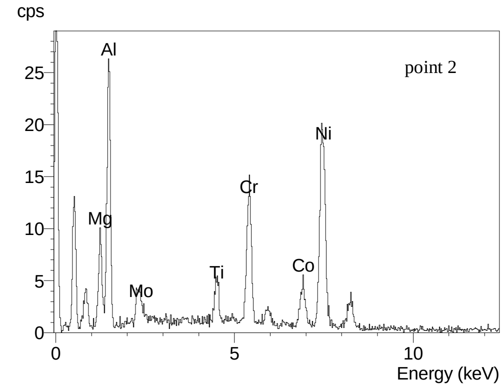
Fig. 5. Local analysis of the edge layer of an H282 alloy ingot melted inalundum crucible (arrows mark the examined points)

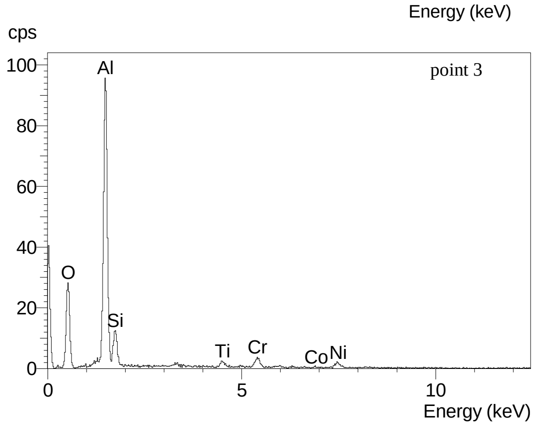
In thecase of zirconia + silicacrucible(crucible no. 2), the edgelayer of the ingot was found to be totally free from the titanium compounds, as illustrated in the graphs in Figure 6. On the other hand, the presence ofaluminumoxides(point 3) and of the compounds of aluminumand siliconwitha low content ofchromium and nickel(points1 and 4) was detected.Underthis layerthere werefinesingleprecipitates of the complex compounds(point 2), andstill deeper the precipitates oftitanium nitrides(point 5).

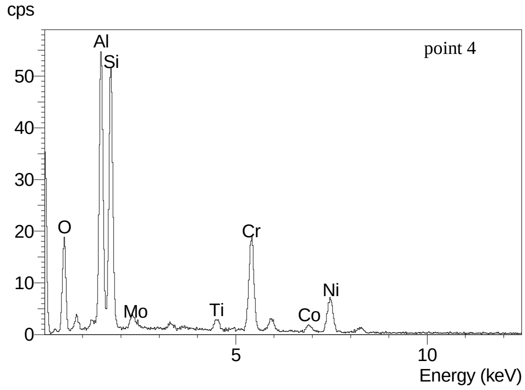












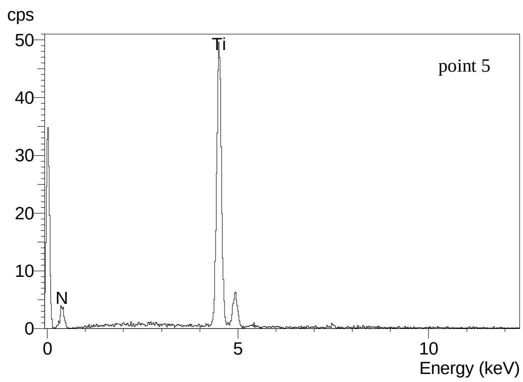
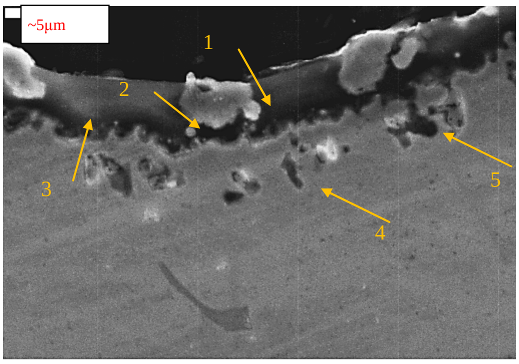
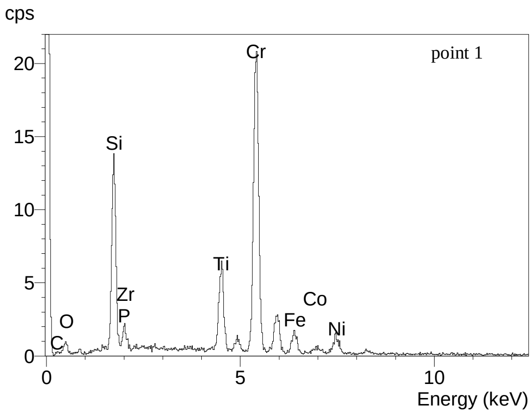
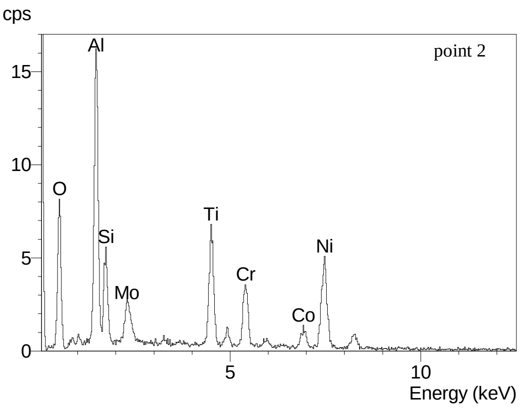


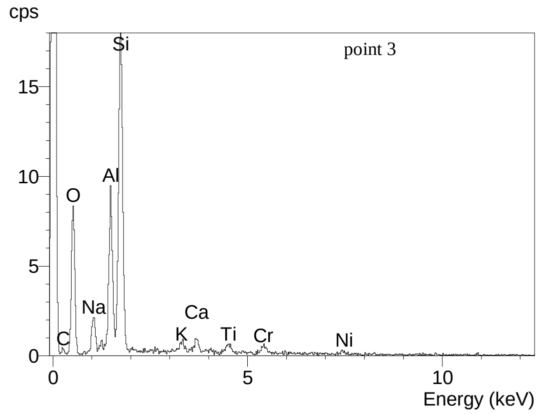
Fig. 6. Local analysis of the edge layer of an H282 alloy ingot melted in zirconia + silica crucible (arrows mark the examined points)

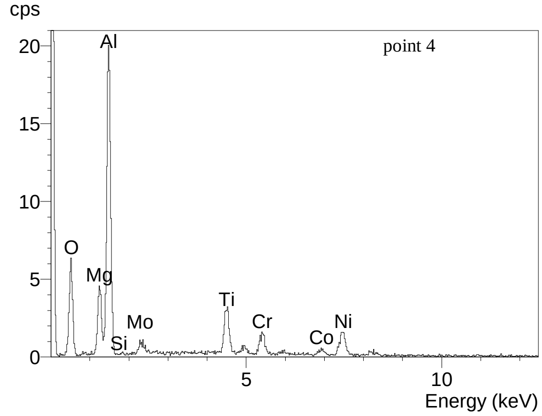
When thecruciblemade of zirconium silicate is used(crucible no. 3), in theedgelayerof the ingot, as shown in Figure7, there are occasionallynear thesurfacesinglecomplex precipitates of the sizeof about1μm, containing mainly chromium and silicon(point1).Intheseprecipitates, other elements also occur, including zirconiumoriginating from the ceramiccrucible. Inthe surface layerof the ingot,aluminum andsiliconoxidesappear (points 2and 3), but the wholelayer isrelativelythin andlesscoherent thanthe same layersformed when crucibles made of zirconia+ silicaorofalundum(especially the latter ones) are used. Under the surfaceof this layerthere are numerous precipitateswith variedchemical composition(points 4 and 5).











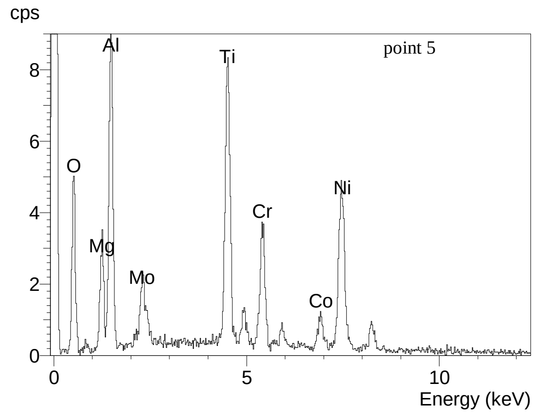


Fig. 7. Local analysis of the edge layer of an H282 alloy ingot melted in zirconium silicate crucible (arrows mark the examined points)

The distribution mapsof elementsanalyzed in the surface layerof the individualingots, shown in Figures8, 9 and 10, confirm that when analundum crucible is used, the layers of aluminum andtitanium oxides are formed at themetal/ceramic interface. A weak interaction withthis layer (dissolution)show elements such as nickel and chromium, iron containedin the liquidH282alloy andcobalt. Noeffect of molybdenum has been observed in this case (Figure8).

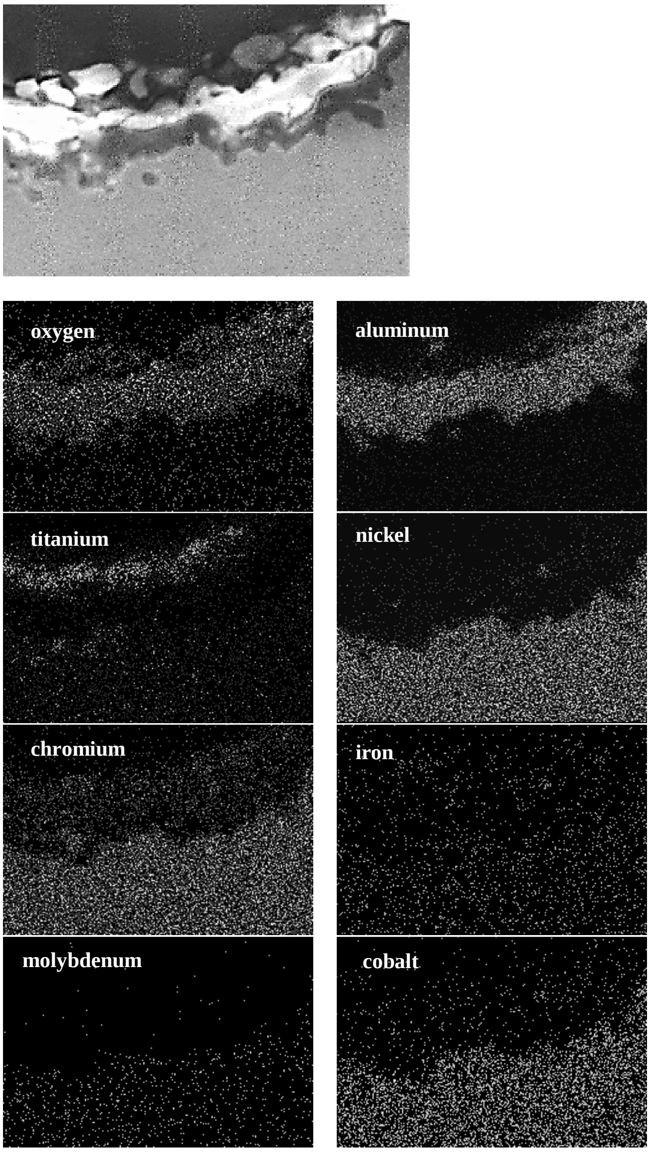


Fig. 8. Distribution of elements in the metal/alundum crucible interface

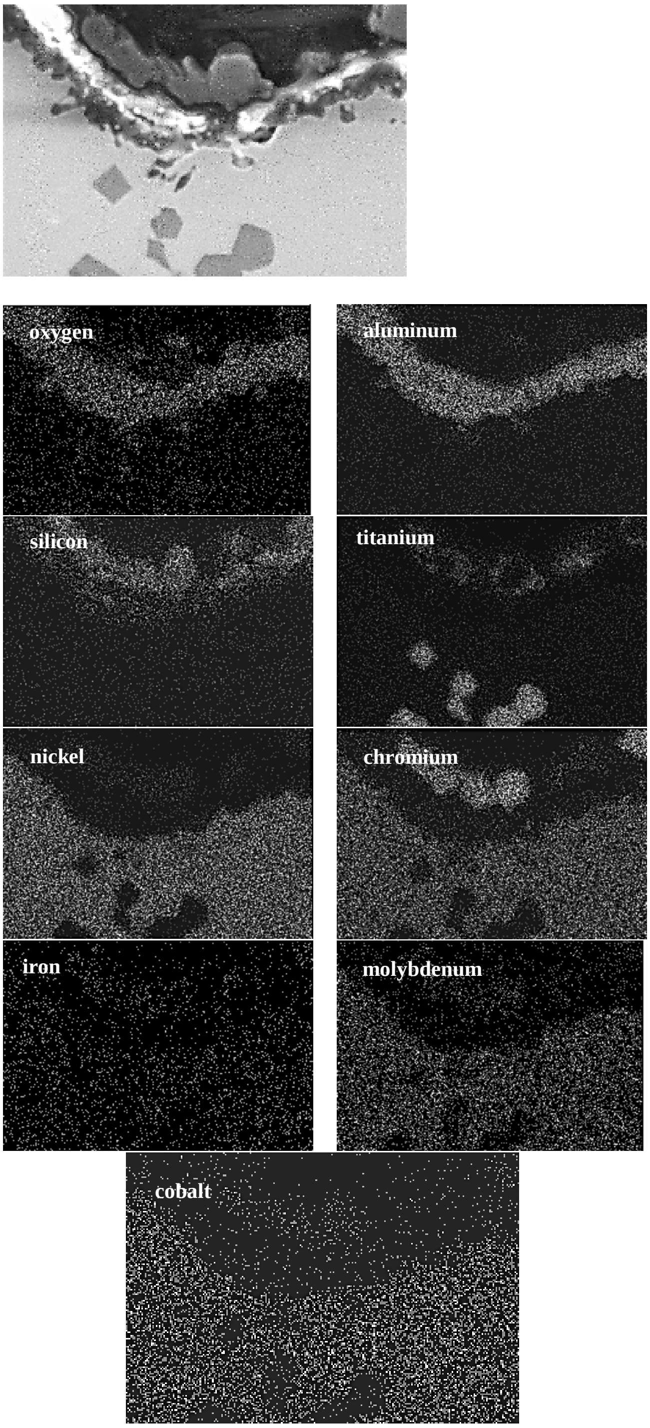


Fig. 9. Distribution of elements in the metal/zirconia+silica crucible interface

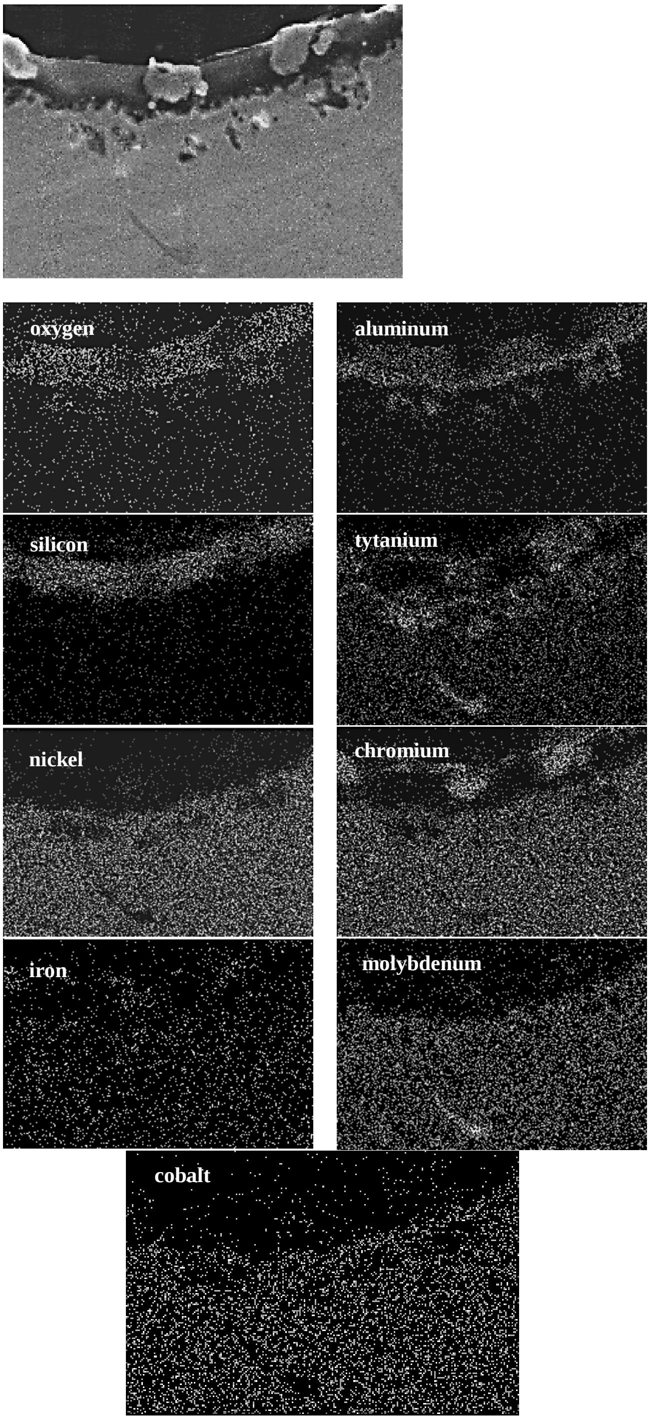


Fig. 10. Distribution of elements in the metal/zirconium silicate crucible interface

In the case of zirconia + silicacrucible,in the outer layerof an ingot, as shown in Figure9, there isa zone of the largeprecipitates ofchromium compounds. A small amount ofoxygen present in these areas and a high content of siliconindicate that, in accordance with theCr-Si phase equilibrium diagram, these can be the intermetallic phases,such as Cr_3Si, Cr_2Si, Cr_3Si_2,CrSi or $CrSi_2$. In these precipitates, certain amount oftitanium is dissolved;otheralloying elements were not found.

Under the layer of the precipitates of the chromium-silicon-titanium phases, there is a layer of aluminum oxides, as indicated by a large amount of bothoxygenandaluminum.

Absence of chromiumand aluminumin the material ofthe ceramiccrucible,on the one hand, and highcontent of these elementsin the H282 alloy,on the other, indicatethat both thechromium-containing layer as well as thelayer of aluminumoxides are formed by a reactionof these elementswith the crucible material at the liquid metal/ceramic interface.

When thecrucible madeof zirconium silicate was used,in the outer layerof an ingot there were some areas with the precipitates similar to those observed in the case of the zirconia + silica crucible. This is shown in Figure 10.

The observed,relativelysmall, amount ofchromium, aluminum andoxygenin the outer layersof an ingotmay indicatea lowerreaction rateat the liquid metal/ceramiccrucible interface, where theH282alloy melt is in contact withthe sole zirconiumsilicate and notwith the whole mixture ofzirconia andsilica.This may result froma smalleramount of oxygenboundin the ceramicscontaining nosilica.

4. Summary and conclusions

The developed methodology of studies of an interaction taking place between the liquid metals or their alloys and ceramic materials used for the refractory lining of induction furnaces enables carrying out tests in a laboratory scale to assess this interaction for the three different ceramic materials in contact with the same metal and under the same time and temperature conditions of the experiment.

By using an indirect charge heating technique, i.e. through a graphite insertplaced in the furnace inductor, the designed and constructed test deviceallows evaluating the intensity of reaction taking place between the molten metal and a ceramic crucible in the case of different cast alloys (alloys of iron, nickel, cobalt, aluminum and copper) and different refractory ceramic materials from which the test crucibles are made.

By placing the designed laboratory devicein a vacuum induction furnace it becomes possible to use a protective atmosphere (vacuum, nitrogen, argon) during the test melting, thereby limiting access of atmospheric oxygen to the melted charge, first, and to the liquid metal, next.

In the conducted experiment, the intensity of reaction of the H282 alloy with the three selected, commonly used in foundry processes, ceramic materials, such as alumina, zirconia+ silicaand zirconium silicate was evaluated.

The H282 alloy contains a large amount of highly reactive alloying elements (aluminum, titanium), and therefore its melting or remelting causes serious problem related with the proper choice of foundry ceramic materials which will contact the liquid metal.

The observations made in the course of the experiments revealed that,as regards the intensity of an interaction with the tested ceramic materials, the contact of molten H282 alloy with the alundumceramics is less favorable than with the ceramics based on zirconium compounds. In the latter case, the use of zirconium silicategives better resultsthan the use of a zirconia + silica mixture, since the former material isless harmful as regards the effect of an interaction at the liquid metal /ceramic material interface (surface pits, reaction products), In spite of this, it is recommended to reduce to an indispensable minimumany contact of the molten H282 alloy with any ofthe ceramic materials (the time of melting as short as possible and the temperature of alloy overheating as low as possible).

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