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Castability and Structure of Dental Alloys on a Nickel Base

A. Zyska *, Z. Konopka, M. Łągiewka, P. Kordas
Foundry Department, Czestochowa University of Technology,
Al. Armii Krajowej 19, 42-200 Częstochowa, Poland
* Corresponding author. E-mail address: zyska@wip.pcz.pl

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Abstract

The results of castability and structures researches of two nickel base alloys - Ceranium CN and Magnum AN applied on casting of the crowns and dental bridges are presented. Studies were carried out on the alloys cast under the centrifugal force to the moulds made by the lost wax method using production line of ROKO. Having regard to a specific technology of casting and possibility of ROKO production line, to the estimation of alloys castability a spiral test was adjusted with a 0,8 mm and a 2,5 mm diameter of test casting. Measuriements executed on a 20 test castings allowed to establish, that castability of Magnum AN alloy was 65 % greater than castability of Ceranium NC alloy. The results of thermodynamics calculations of the equilibrium and nonequilibrium crystallization (Scheil model) of the investigated alloys are presented too. The characteristic temperatures of phase transformation and forecast phase composition of alloys for both kind of crystallization were calculated. It is established after structural supervisions, that the investigated alloys crystallize in dendryte form and in centrifugal casting conditions have cooling rate sensivity and inclination to texture structure forming in outmost layer of casting. Phase composition of alloys corresponds to the results of thermodynamics calculations of the nonequilibrium crystallization conditions.

Keywords: Dental alloys, Centrifugal casting, Technology of the lost model, Castability, Structure of base nickel alloys

1. Introduction

Metallic materials present the most important group of biomaterials applied in dental prosthetics and used to realization of two basic actions: reconstruction of failing teeth and correction and maintenance of function of organ of mastication [1,2]. Precious and common metals also their alloys are used in stomatology according to the norm of ANSI-ADA [1,3]. Precious metals such as gold and platinum are used for many years, however taking into account their high price and subzero properties of endurance their application considerably limited. Instead of them strong position in dental practice found the alloys, based on a cobalt, nickel and titan [1,4-10]. Those alloys are appointed mainly to implementation of fixed dental bridges, crowns and implants veneered with ceramics, composite or polymer [11-17]. Castings of dental prosthetic appliances are carried out in the lost wax technology in combination with the centrifugal casting method or vacuum-pressure method [18,19]. The choice of technology is aimed at obtaining castings with as high a shape-dimension accuracy and low surface roughness. During forming the ceramic masses of very high temperatures resistant and a high pure waxes are used. The waxes have also high stiffness and small contraction, to prevent possible deformities of the modeled construction and provide her large detail of dimensional accuracy. Casting moulds are carried out usually in the special metallic or silicon rings [20-22]. The quality of castings for prosthetics depends on physical and technological properties of dental alloys. Those properties have direct or indirect influence on the corresponding operating parameters of castings, corresponding their structure, detail and stability and dimensional accuracy. From the above-mentioned relations the casting alloys used in stomatology must answer next queries:

- chemical composition of alloy must provide accordingly high strength, hardness and wear resistance,
- properties and structure of alloy must not change during the whole period of exploitation,
- alloy should has good casting properties, eg. corresponding castability, small casting contraction, small propensity to the origin of tensions also absorption of gases, small solidification rate sensivity and origin of texture, shortage of inclination to segregation.
- alloy must be characterized lightness of tooling and welding possibility [22, 23].

Except that, every alloy must be marked biotoleration, matching to veneering material and resistant to corrosion [1,2,14]. Dental alloys require maintenance of meticulous norms in relation to chemical composition also totality of the technological process related to their products. They are produced usually from pure initial components, taking into account the methods of drowning, at application of the controlled atmosphere (e.g. in vacuum or in atmosphere of argon). The alloys on the base of common metals as: Ni-Cr, Ni-Cr-Be, Ni-Cr-Fe also Co-Cr are most popular alloys. They are applied in daily practice, primarily because of the low price and the relatively small percentage of failures associated with the process of bonding to ceramics or composites [24]. Nickel alloys are used as an alternative for the cobalt alloys. Nickel alloys have advantageous mechanical properties, very good corrosion resistance and also good casting properties. Chemical composition of nickel dental casting alloys used to the prothetic reconstruction is determined by the norm of ISO 6871-2.

This article demonstrates part of complex works from an area of technological and useful properties of dental alloys on a base nickel. The aim of these works was an estimation of castability and structures of commercial alloys of Ni-Cr also Ni-Cr-Fe, cast under the centrifugal stamping to the forms executed by the lost wax method. Experimental part of work was realized in the conditions of prosthetic workshop at the use of materials and devices in dental prosthetic production.

2. Material and methodology

Two dental commercial alloys of Ceranium NC and Magnum AN were used in investigation. Chemical composition of the investigated alloys is presented in a table 1.

Table 1.
Chemical composition of dental alloys

Alloy	Content of element, % mass				
	Ni	Cr	Fe	Mo	Si
Ceranium NC	66	24	<0,5	10	<0,5
Magnum AN	28	22	42	3	4

Moulds for castings of castability test and structural researches are executed by the method of the lost wax on the technological line ROKO according to the procedures worked out for the small dental casting. The models of spiral with dimensions: 10mm/50mm/22mm (pitch/high/diameter of the coil) were formed from wires of hard wax about the diameter of a 0,8 mm and a 2,5 mm of Finowax and Bilkim firms. On length of spiral measuring markers are inflicted on distance that a 10 mm each. The executed wax models were placed in the moulding ring of about the diameter of a 90 mm and drowned in-bulk SHERA mass. This mass is prepared on basis of quartz sand flour bonded by the suspension of silica in solution of ethyl orthosilicate. The time of working was about 8 minutes, and time of hardening of 30 minutes.

Heat treatment of ceramic moulds was realized at permanent rate of heating of 7^0C/min. Two stages of heating was applied in the temperature of 250^0C in 30 minutes (wax melting) and in the temperature of 960^0C in 15 minutes (forms hardening for achieve required mechanical properties). Melting alloys and pouring casting moulds were conducted on a device to casting under the centrifugal stamping with the induction system of melting - ROTOCAST. Pouring temperatures of Ceranium NC and Magnum AN alloys were accordingly 1420^0C and 1440^0C. After time of 90 minutes, test castings were remove from a moulds and the castability was measured.

Castability is a basic casting property that decides about possibility of the use of alloys of metals on casting. For the method of casting under the centrifugal pressure the castability test sample normalized to this day is not set. Within the framework of work, it is resolute adopted the spiral fluidity test casting often applied in technology of the gravity casting. The choice of an experience method was limited size of casting mould - the maximal diameter of moulding-ring on the ROKO line took away a 90 mm. Additional difficulty during realization of experiment was setting of mould cavity size – section of channels that will provide the correct measurement. From this relation two spiral castability test samples, that allow to do the comparative estimation of alloys identically, are applied, how also to define possibility of implementation of the long thin walled (about the of wall thickness a 1 mm).

Castability measurements were done on 20 test castings. The five test castings for aech kind of alloy and spiral diameter were carried out. Then from castings of spiral about the diameter of a 2,5 mm samples for structure alloys investigations were cut from their middle parts of casting. The microscopic observations were executed on microsections etched by royal water at the use of light microscope NIKON ECLIPSE MA 200. Before a structural analysis the thermodynamics calculations of crystallization process of investigated alloys were carried out. The analysis of solidification process of alloys was executed at the use of the computer program ThermoCalc with application the base of these thermodynamics data SSOL.

3.1. Results of castability researches

Examples of spiral castability test sample and also mean values of Ceranium NC and Magnum alloys from measurements were presented in Figs. 1-3.

Fig. 1. Spiral test castings of 0,8 mm diameter
a) Ceranium NC alloy, b) Magnum AN alloy

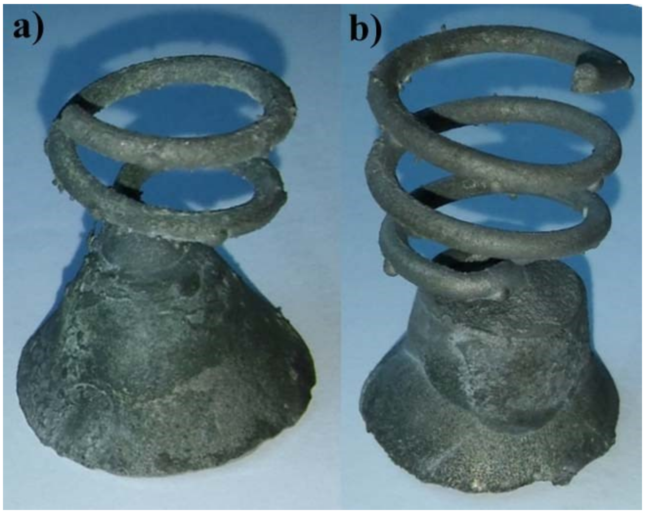

Fig. 2. Spiral test castings of 2,5 mm diameter
a) Ceranium NC alloy, b) Magnum AN alloy

From a diagram 3 it follows simply, that the Magnum AN alloy is characterized considerably anymore castability than Ceranium NC alloy, especially when comparison is accomplished on a spiral attempt about the diameter of cut of puttee of 2,5mm. That advantage is also visible on the second technological test, here a difference is not such expressive here. It was caused mainly very rapid cooling and solidification of stream front of liquid metal in the very thin channels of casting mould. It is confessed in relation to the above-mentioned, that spiral tests of castability about the diameter of a 2,5 mm is more suitable. This spiral test is less vulnerable on the rate of cooling.

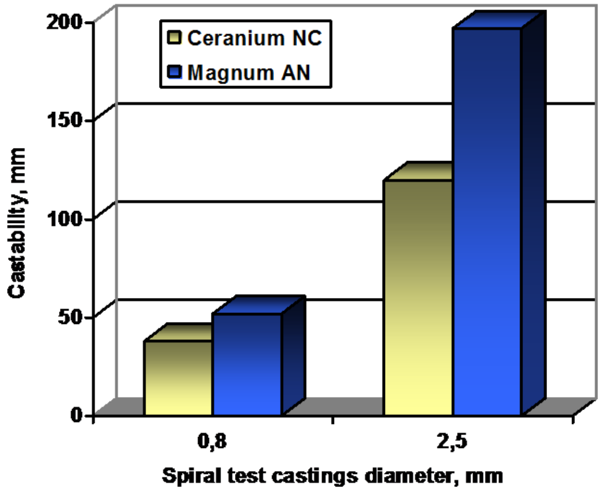

Fig. 3. Castability of Ceranium NC and Magnum AN alloys

For this test, mean length of spiral casting from the Magnum AN alloy took away a 197 mm, and in case of Ceranium NC alloy this length is a 120 mm. Applying the percent criterion of estimation, it is possible to establish, that castability of Magnum NC alloy is about 65 % greater from castability of Ceranium NC alloy. From the second castability test arises up but, that the Magnum AN and Ceranium NC alloys can be assigned for thin walled castings with 1 mm size of wall and 50 mm i 40 mm in length respectively.

3.2. Estimation of solidification on the thermodynamics calculations base

The numerical simulations were carried out on the model of the equilibrium solidification and also with solidification model with the diffusionless segregation in a solid phase (Scheil model). The characteristic temperatures of phase changes also forecast phase composition of alloys are certain in the effect of calculations. Results as curves of solidification are presented in Fig. 4 and 5.

It follows from the conducted thermodynamics calculations, that the alloy of Ceranium NC in the equilibrium conditions solidifies as a monophase (phase of α), the likwidus temperature T_L takes away 1392^0C and solidus temperature $T_S=1383^0$C. As a result of diffusionless segregation of alloying components in a primary phase, the type of solidification curve (Fig. 4, line Scheil) changes and in a consequence at the end of solidification a phase σ precipitates. Phase α is a solid substitutional solution of Cr, Mo in Ni, and phase σ is a solid substitutional solution of Ni and Mo in Cr.

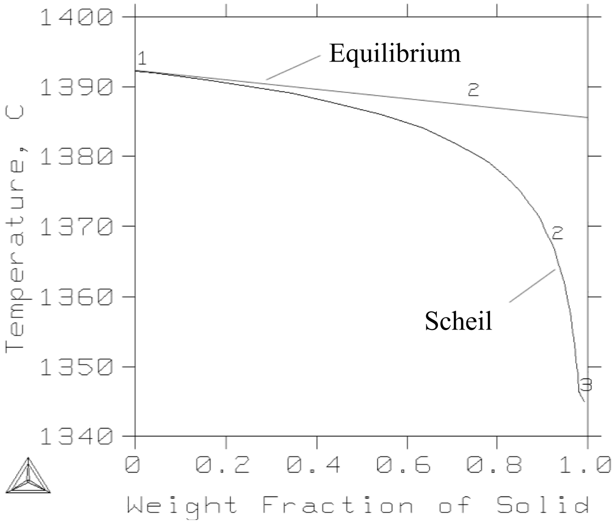

Fig. 4. Equilibrium and non-equilibruim solidification of Ceranium NC alloy
1–liquid, 2–liquid+phase α, 3–liquid + phase α+ σ phase

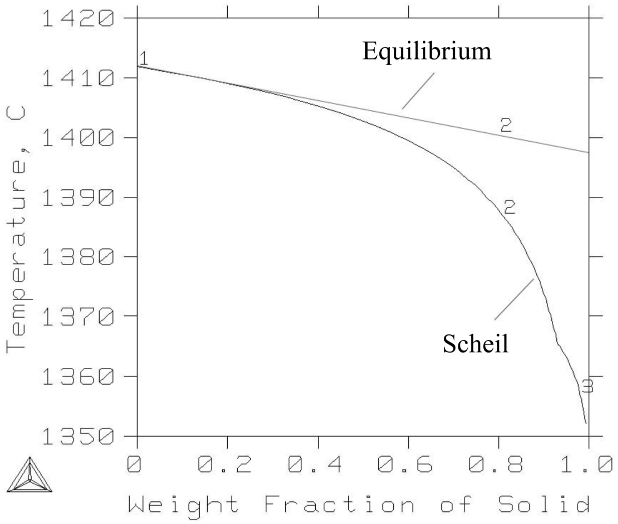

Fig. 5. Equilibrium and non-equilibruim solidification of Magnum AN alloy
1–liquid, 2–liquid+ γ phase, 3–liquid+ phase γ+ Cr_3Si phase

The analogical calculations executed for the alloy of Magnum AN educed, that solidification starts in the temperature $T_L = 1412^0C$, in the equilibrium conditions from a liquid phase only one phase γ precipitates and solidification finishes in the temperature $T_S = 1395^0C$. From the numerical simulation executed leaning on a Scheil model arises up, that the diffusionless segregation in this alloy causes a precipitating of Cr_3Si phase from the last portions of liquid. In the Magnum AN alloy, the phase of γ is presented by a solid substitutional solution of Ni, Cr, Si and Mo in Fe is an alloyed austenite, and Cr_3Si then an intermetallic phase is about chemical composition of 85% mass of Cr and 15% mass of Si.

3.3. Researches of structure

The typical microstructures of Ceranium NC and Magnum AN alloys observed near edge and in middle part of casting are shown on pictures 6 and 7. It follows from the conducted supervisions, that both investigated alloys solidifies as a dendritic and in the conditions of casting under the centrifugal stamping find out propensity to creation of texture structure in the surface layer of casting. The educed shapes and system of arms of main dendrites are the effect of parallel increase of crystals in the direction of opposite to direction of heat transfer. Sensitivity on solidification rate (section sensitivity) and propensity to creation of casting texture related directly to the initial period of alloys solidification and by the origin of nucleus. When the amount of nuclei increase, the number of dendritic crystals increases and together with combination with crystallization purposeful from the wall of mould amount of primary phase grains has anisotropic character. An origin of texture in the stomatological casting is the unprofitable phenomenon as promotes to propagation and development of cracks along dendrites [16]. Based on the observation of entire cross-sectional views, it was found that structure of Ceranium NC alloy exhibited a greater number of dendritic grains, smaller longitudinal and transverse dimensions of main dendrites arms, and a smaller distance between the secondary arms (DAS).

Greater sensitivity on cooling rate and propensity to creation of directing structure of Ceranium NC alloy in relation to the Magnum AN alloy can be also observed after comparing pictures the structures executed on a casting edge and in middle part of casting. In case of Magnum AN alloy arrangement of dendrites and mutual their drafting in middle part of casting has casual character typical for by volume crystallization, but in the Ceranium NC alloys the mode of crystals specifies on motion of crystallization about anisotropic character.

The Ceranium NC and Magnum AN alloys in the equilibrium conditions solidify as monophase. Estimating the results of structural researches it follows to establish, that Magnum AN alloy in the applied solidification conditions-high solidification rate of arising out of technology of the centrifugal casting and small thickness of walls of casting have two-phase construction that is consists of the dendrites of γ phase and located in interdendritic spaces Cr_3Si phase. Appearance of Cr_3Si phase in the structure of casting is caused nonequilibrium solidification.
As a result of alloying elements segregation in a solidification solid phase, their increase of content comes in a liquid phase. Enriching of liquid in the alloying elements in the final period of solidification is such high, that from the last portions of liquid phase a phase precipitates Cr_3Si crystallize. Any X-ray diffraction was not performed for the identification of Cr_3Si phase, but the marked areas in Fig. 7 indicate a high probability of its occurrence. Ceranium NC alloy in the applied solidification conditions are less prone to microsegregation and no phase σ is observed in its structure as indicated by the results of thermodynamic calculations for Scheil model.

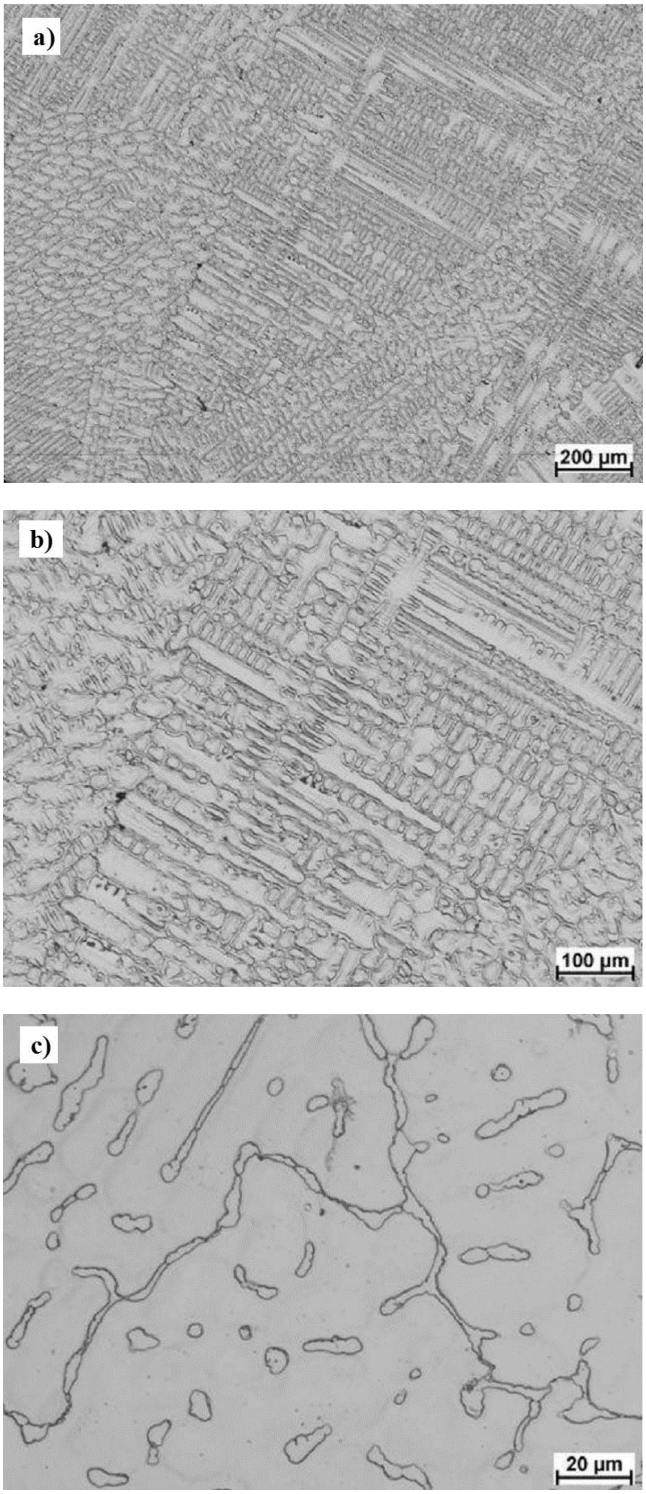

Fig. 6. Structure of Ceranium NC alloy
a) edge of sample, b), c) centre of sample

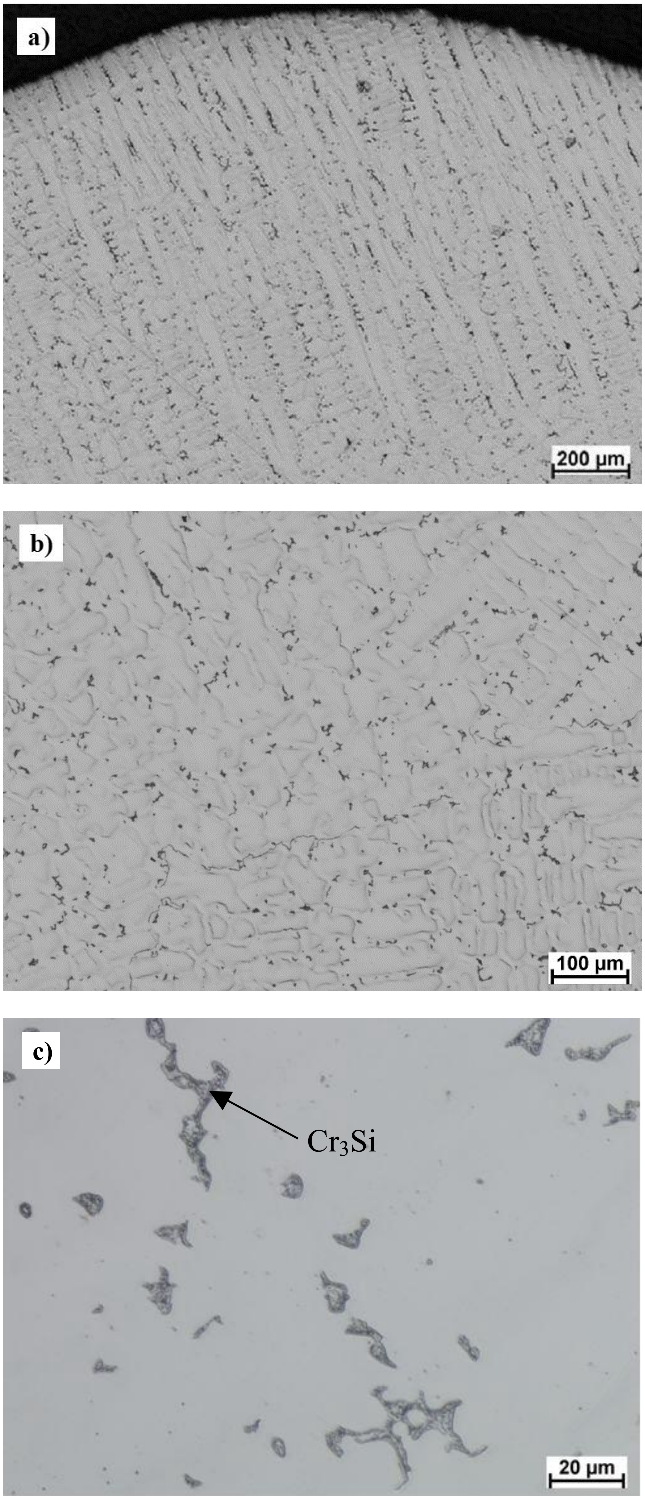

Fig. 7. Structure of Magnum AN alloy
a) edge of sample, b), c) centre of sample

4. Eventual statements

1. The spiral test adopted to centrifugal technology about the 2,5 mm diameter of casting allows the correct measuring of alloys castability. Castability of Magnum AN alloy is on close 65% higher from castability of Ceranium NC alloy.
2. The studies have confirmed that lost wax technology in combination with the method of casting under the centrifugal stamping does possible making of the long (40 - 50 mm) thinwalled castings from the Ceranium NC and Magnum AN alloys.
3. In the applied conditions of casting and solidification the investigated alloys on a base nickel find out propensity to the origin of texture in the surface layer of casting. The anisotropic growth of primary crystals is stronger designated in casting made from the Ceranium NC alloy.
4. As a result of microsegregation of alloying constituents in a solid phase during solidification, nominal the monophase alloy of Magnum AN have a two-phase structure that is composed with γ and Cr_3Si (ThermoCalc, Scheil model). The microsegregation in Ceranium NC alloy is not intense and it has a monophase structure.

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