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(54) Title: SUPER ALLOY PREVENTING RADIATION LEAKS

(57) Abstract: The invention relates to a superalloy used in nuclear power plants, boron neutron treatment units, laboratory research and investigation studies, storage and transport of radioactive substances, and armouring shielding materials against radiation leaks in space vehicles; which consists of nickel (Ni), chrome (Cr), iron (Fe), rhenium (Re), and tungsten (W) materials; and can be used as armouring shielding material against gamma radiation leaks in the range of 1.25 MeV - 7 MeV energy interval and neutron radiation leaks in the range of 0.4 KeV - 4.5 MeV energy interval.



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DESCRIPTION**Super Alloy Preventing Radiation Leaks****5 The Related Art**

The invention relates to a superalloy used for armoring shielding materials against radiation leaks in nuclear power plants, boron neutron treatment units, laboratory research and investigation studies, storage and transport of radioactive substances
10 and in space vehicles.

The invention, particularly relates to a superalloy formed of nickel (Ni), chromium (Cr), iron (Fe), rhenium (Re), and tungsten (W) materials and can be used as mooring shielding material against gamma radiation leaks in the range of 1.25 MeV -
15 7 MeV energy interval and neutron radiation leaks in the range of 0.45 keV - 4.5 MeV energy interval.

The Prior Art

20 In order to prevent gamma and neutron radiation leakage in nuclear applications (nuclear power plants, boron neutron therapies, research and investigative studies, space vehicles, etc.), 316LN steel (10 % Ni + 66,725 % Fe + 18 % Cr + 2 % men + 2 % Mo + 0.2 % N + 0.03 % C + 1 % say + 0.045 % P) is widely used as armor material. However, lower rates of nickel (Ni) and chrome having the high absorption
25 power of the neutron and gamma radiation used in production of this steel leads to inadequate armoring of neutron and gamma radiation. When the thickness of the material is increased to eliminate this negativity, cracks occur in the material exposed to high temperatures, which causes leakage.

In the literature, one of the patents about this subject is the application No.
30 EP2196553B1. In the abstract of this application, it is disclosed that, "the invention relates to machine components or structural parts made of steel alloy annealed by heat treatment and having a strength of more than 2000 [MPa] for variable mechanical loads, up to a temperature of 160 °C. In order to achieve enhanced long-lasting, fatigue safety, and a high E-modulus characteristics of the material at high

loads, the chemical composition of the steel alloy according to the invention should comprise (% by weight) one or more of 0.48 to 0.55 Carbon (C), 0.18 to 0.25 Silicon (Si), 0.35 to 0.45 Manganese (Mn), 4.40 to 4.70 Chrome (Cr), 2.90 to 3.10 Molybdenum (Mo), and 0.72 to 0.77 Vanadium (V), and even as residue, at most 0.005 phosphorus (P), at most 0.001 sulphur (S), at most 0.1 Nickel (Ni), at most 0.01 Copper (Cu) at most 0.01 Cobalt (Co), at most 0.005 Titanium (Ti), at most 0.01 aluminium (Al), at most 0.003 nitrogen (N), at most 0.002 oxygen (O), at most 0.001 calcium (Ca), at most 0.001 magnesium (Mg), at most 0.005 zinc (Zn), at most 0.005 iron (Fe) and impurities etc. side and pollutant elements."

In the summary of the application No. TR201407309, it is disclosed that: "The invention is a weldable, high temperature oxidation resistant alloy having cracking sensitivity and strain aging cracking at a low hardening rate. The alloy comprises 25% to 32% weight percent iron, 18% to 25% weight percent chromium, 3.0% to 4.5% weight percent aluminium, 0.2% to 0.6% weight percent titanium, 0.2% to 0.4% weight percent silicon, 0.2% to 0.5% weight percent manganese, and the remaining percentage includes nickel and other foreign substances. The content of Al + Ti should be between 3.4 and 4.2, and the Cr / Al ratio should be between about 4.5 and 8." .

As a result, the above said drawbacks and the inadequacy of the prior art solutions about the subject have necessitated an improvement in the related technical field.

Purpose of the Invention

The present invention relates to a superalloy preventing radiation leakage, which meets the above said requirements, eliminates all of the drawbacks, and brings some additional advantages.

The primary purpose of the invention is to obtain a superalloy having high neutron and gamma radiation absorption characteristics according to the results of experimental and quasi-experimental Monte Carlo Simulation (GEANT4) by Ni, Cr, Re, and W used in its content. Use of high rates of nickel and chrome both provides a good corrosion resistance as well as increasing the neutron and gamma radiation

absorption power of the material. Use of the refractory elements rhenium and tungsten increases the neutron and gamma radiation absorption power of the material even more. Since these refractory metals move the melting point of the alloy to an advanced level, they provide ease of use and safety at high temperatures.

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A purpose of the invention is to increase safety precautions by ensuring that the obtained superalloy provides safe armouring in nuclear applications.

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Another purpose of the invention is to reduce the material thickness with the obtained superalloy. In this way, the problem of cracking at high temperatures is substantially eliminated.

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Another purpose of the invention relates to a superalloy which is used as armouring shielding material against radiation leaks, and which is easy to produce and can be produced in short time.

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In order to achieve the above said purposes, a superalloy is developed, which consists of nickel (Ni), chrome (Cr), iron (Fe), rhenium (Re), and tungsten (W) materials; and can be used as armouring shielding material against gamma radiation leaks in the range of 1.25 MeV - 7 MeV energy interval and neutron radiation leaks in the range of 0.4 KeV - 4.5 MeV energy interval.

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The structural and characteristic features of the invention and all of its advantages shall be understood better with the figures and the detailed description given below in reference to the figures, and therefore, the assessment should be made by taking into account the said figures and detailed explanations.

Detailed Description of the Invention

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In this detailed description, the preferred embodiments of the super alloy preventing radiation leaks are only disclosed for better understanding of the subject without forming any limiting effect.

The invention is a superalloy obtained from nickel (Ni), chrome (Cr), iron (Fe), rhenium (Re), and tungsten (W) to prevent radiation leaks. Below are the general characteristics and the contributing characteristics to the alloy by the materials forming the superalloy:

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Nickel (Ni): The alloy element nickel forms Ni - Mo or Ni - Cr - Mo alloys, and especially Ni-Cr alloy. It increases the resistance of the alloy against heat and scaling. When used in combination with chrome, it increases the hardness, ductility and high fatigue resistance of the alloy. It has a high gamma and neutron radiation absorption impact section.

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Chrome (Cr): It is the element that is added the most into steels and alloys. Chrome added to alloy and steel increases the hardness of the alloy or steel. By slowing down the conversion speed, it also increases the depth of hardness. If chrome is used at 25 % ratio, it forms a bright image on the surface of the material, and by forming an oxide layer on the surface, it increases the resistance of the material against corrosion by means of this oxide layer. It also increases the tensile strength and temperature resistance of the alloy. It generally forms better alloys with nickel. It has a high gamma and neutron radiation absorption impact section.

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Iron (Fe): Iron is the most commonly used one among all metals, and constitutes 95 % by weight of the metals produced all over the world. Steel is the most well known iron alloy. Steels used in nuclear reactors (316LN) contain about 67 % iron. Iron is not resistant to corrosion due to the oxidation occurring on its surface. In order to protect iron from corrosion, its surface is coated with a non-permeable paint or elements such as nickel and chrome.

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Rhenium (Re): Rhenium, having significantly increased production and applications in recent years, is a refractory metal with a very high melting point and a very good mechanical and electrical properties. It is used in the production of high temperature resistant alloys. It is also used to enhance the properties of tungsten and molybdenum alloys. It also has very high gamma and neutron radiation absorption impact section. Therefore, it is a very good gamma and neutron radiation absorber.

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Tungsten (W): Tungsten is an element that increases the strength of the steel and alloy, to which it is added. In tool steels, it ensures maintaining the hardness of the cutting edge, extension of the tool life, and high temperature resistance. It is used in making of heat-resistant steels, since it prevents the steel from tempering and losing its hardness at high operating temperatures. It also has very high gamma and neutron radiation absorption impact section. Therefore, it is a very good gamma and neutron radiation absorber.

In the below given table, characteristics of the materials forming the superalloy according to the invention are given:

Table 1. Characteristics of the materials used in the alloy fabrication

Material	Density g/cm³	Melting Point (°C)	4.5 MeV neutron macroscopic impact section (cm⁻¹)	1.25 MeV gamma linear absorption coefficient (cm⁻¹)
Rhenium	21.02	3150	0.431	1.144
Chrome	6.9	1857	0.309	0.377
Nickel	8.908	1455	0.327	0.484
Iron	7.86	1538	0.321	0.417
Tungsten	19.3	3482	0.428	1.040

In the below given Table 2, the preferred and usable weight percentages of the substances forming the superalloy according to the invention are given.

Table 2. Weight percentages of the substances forming the superalloy

Component Name	Preferred amount by weight (%)	Usable amount by weight (%)
Nickel (Ni)	50	45-50
Chrome (Cr)	25	20-25
Iron (Fe)	15	10-15
Rhenium (Re)	5	5-10
Tungsten (W)	5	5-10

The method of obtaining the superalloy according to the invention is as follows:

First of all, considering the percentages of nano-sized nickel (Ni), chrome (Cr), iron (Fe), rhenium (Re), tungsten (W) powders determined by Monte Carlo simulations; the usable weight ratios given in Table 2 are mixed until a homogenous state is reached. The mixing operation is carried out for about 1-2 hours using a mixer. Before the pressing process, 0.5 % of paraffin is added to the prepared powder mixtures as a lubrication process. By using the lubricant, the friction between the mass of powder and the tool surfaces of the press machine and the mold walls is reduced, so that the powders can easily slide during compression. With the lubrication process, a uniform density is formed from the lower surface to the upper surface of the material. Another advantage of the lubrication process is that the pressed material is easily removed from the mold. Afterwards, the homogeneously mixed powders are pressed under 15-20 tons of pressure, using a pellet press machine. The pressed material is annealed at 1200 to 1500 °C (preferably 1300 °C) for 4 hours, using an annealing furnace. Following the annealing operation, the superalloy obtained is left to cool down.

The obtained super alloy can be produced in many shapes such as plates or pellets in any desired thickness, according to the area of usage. The material is extremely resistant to chemical corrosion. Moreover, the superalloy can be used at temperatures between 1380°C- 1600 °C.

The superalloy produced can be used for gamma and neutron radiations with the following energy levels:

- with gamma radiation of 1.25 MeV and 7 MeV energy
- 10-20 MeV > E > 100-200 keV: Fast neutrons
- 100 keV > E > 0.1 eV: Epithermal neutrons
- E ~ kT ~ 1/40 eV: Thermal / Slow neutrons
- E ~ meV ~ µeV: Cold and ultracold neutrons

The super alloy produced is subjected to pressure resistance test under pressures of 25 tons in a 30-ton hydraulic press machine. Moreover, sulphuric acid abrasion tests are also carried out in a sulphuric acid (H₂SO₄) pool for 24-48 hours.

The obtained final superalloy is subjected to 4.5 MeV fast neutron radiation absorption experiments by Am241 - Be fast neutron source and neutron detector. This experiment is also performed for the 316LN steel used in the prior art, and the following comparative results are obtained:

- According to the GEANT4 kit of Monte Carlo simulation program, for the 316LN steel used against a gamma radiation of 1.25 MeV energy; the linear absorption impact section was found to be 0.32273 cm^{-1} and the mass absorption impact section was found to be $4.2841 \text{ mm}^2 / \text{g}$. For the super alloy according to the invention, under 1.25 MeV energy gamma radiation, the linear absorption impact section is 0.49844 cm^{-1} and the mass absorption impact section is $5.3172 \text{ mm}^2 / \text{g}$.
- For the 316LN steel used against a gamma radiation of 7 MeV energy; the linear absorption impact section was found to be 0.235577 cm^{-1} and the mass absorption impact section was found to be $2.9472 \text{ mm}^2 / \text{g}$. For the super alloy according to the invention, under 7 MeV energy gamma radiation, the linear absorption impact section is 0.29196 cm^{-1} and the mass absorption impact section is $3.1146 \text{ mm}^2 / \text{g}$.

According to these results, the superalloy according to the application seems to have better armouring ability for a gamma radiation of 1.25 MeV and 7 MeV energy level. The big linear absorption coefficient in gamma armouring is an indication that the material acts as a good armour.

- For 4.5 MeV fast neutrons, the total macroscopic impact section of the 316LN steel is 0.309224 cm^{-1} . The total macroscopic impact section of the superalloy according to the present application for the neutrons of the same energy level is 0.371489 cm^{-1} .
- Also, in the experimental measurements, while the equivalent dose is reduced to $1.175673 \text{ } \mu\text{Sv} / \text{h}$ from neutron source of 4.5 MeV energy speed for samples of the same size, the equivalent dose from the superalloy source according to the present application is reduced to $0.525218 \text{ } \mu\text{Sv} / \text{h}$.

According to these experimental results, the superalloy according to the present application reduced the dose against 316LN steel by about half. Accordingly, the

superalloy has exhibited an excellent absorption performance against neutron radiation in this energy level.

- While the melting point of 316LN steel is 1345°C - 1440 °C, the melting point of the super alloy according to the present application is 1380 °C - 1500 °C.

This indicates that the high temperature resistance of the super alloy is better than the 316LN steel.

CLAIMS

1. A superalloy used for armouring shielding material against radiation leaks
5 comprising nickel (Ni), chrome (Cr), iron (Fe), rhenium (Re), and tungsten (W).
2. A superalloy according to Claim 1, characterized in comprising said nickel in 45-
50 % by weight ratio, said chrome in 20-25 % by weight ratio, said iron in 10-15 % by
weight ratio, said rhenium in 5-10 % by weight ratio, and said tungsten in 5-10 % by
10 weight ratio.

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
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ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G21F C22C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KORKUT TURGAY ET AL: "Study of neutron attenuation properties of super alloys with added rhenium", JOURNAL OF RADIOANALYTICAL AND NUCLEAR CHEMISTRY, AKADEMIKI KIADO RT, HU, vol. 306, no. 1, 17 March 2015 (2015-03-17), pages 119-122, XP035542140, ISSN: 0236-5731, DOI: 10.1007/S10967-015-4063-Z [retrieved on 2015-03-17] the whole document -----	1,2

☐

Further documents are listed in the continuation of Box C.

☐

See patent family annex.

* Special categories of cited documents:

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