Original Article: Examining the Arrangement of Cermet Positions and its Types to Improve Resistance to Deformation and Fracture

Frank Ablin Derosow

Department of Chemical Engineering, Calgary University, Canada

Use yor device to scan and read the article online

Citation F Ablin Derosow, **Examining Cermet's (a Homogeneous Mixture of Metals or Alloys or One or More Ceramic Phases),** *EJCMPR* . 2023; 2(4):197-206.

https://doi.org/10.5281/zenodo.8282586

Article info:
Received: 10 May 2023
Accepted: 25 August 2023
Available Online:
ID: EJCMPR-2308-1095
Checked for Plagiarism: Yes
Peer Reviewers Approved by:
Dr. Frank Rebout
Editor who Approved Publication:
Dr. Frank Rebout

Keywords:
Cermet position arrangement, strength improvement, deformation, pressure, solid solution

ABSTRACT

A major improvement in the resistance to deformation in TiC cermet's and at the same time as a reduction in brittleness is possible by changing the arrangement of the bonded alloy or the carbide phase or both. to give an example of an optimal adhesive composition is 22.5% nickel, 10% molybdenum, and approximately 7% aluminum. Improvement of the compressive yield strength of the carbide phase is achieved by forming a solid solution of TiC with 10% by weight of Vc. The addition of approximately 10% by weight of TiM greatly increases the deformation resistance of cermet. It is believed that this increase is ultimately the result of two factors, the effect of re-purification of the grains and the hardening of the carbide phase in the solid solution. If the ratio of titanium nitride to titanium carbide increases, carbo-nitride undergoes changes in its structure, which under controlled conditions can greatly improve the strength and fracture toughness of cermet. In the early 1970s, it was discovered that in the ternary systems Ti-MO-C-N and Ti-W-C-N there is a miscible gap in complete solid solutions between MON, MOC, TiN, and TiC under controlled, single-phase process conditions. Homogeneous solid solution breaks spontaneously or immediately into two similar phases that have close network parameters, but have different chemical compositions.

Introduction

Cermet's α is necessarily titanium carbonitride, which actually contains all the nitrogen in the original mixture [1-3]. The ά phase contains only a small amount of nitrogen, but almost all of the molybdenum and tungsten [4-6]. The microstructure of vacuum sintered cermet's contains nickel-molybdenum bonded carbonitride as hard particles and also has a titanium-nitrogen rich α carbonitride core with a rim of molybdenum ά for better wettability with the adhesive phase during liquid phase sintering under It shows emptiness and produces cermet with very high resistance. Increased improvement in resistance to deformation and fracture toughness is obtained by arranging more cermet states without changing essential structural aspects [7-9].

***Corresponding Author: Frank Ablin Derosow** (*fa.derosow@gmail.com*)

Currently, optimization tends to remove hard components as well as glue. In the past, titanium carbonitride solid solution was diluted with MO_2C, NbC, TiC, VC, WC alone or in combination up to forty percent by weight. The glue is a solid solution of nickel and cobalt, which is used in different proportions, especially 10 to 15 percent by weight of the total cermet composition [10-12]. The alloy is resisted by adsorbed molybdenum and titanium, which are released by the hard particles during liquid phase sintering. The added aluminum initially participates in increasing the strength, especially at the temperatures encountered by the cutting tool [13-15]. It is also possible that there are cermet's that show completely different microstructures. Hexagonal plates with sizes in the range of micrometers can be distributed within spherical grains or other coaxial shapes, and both hard components are connected to the softer metal [16-18].

These microstructural cases are both the result of the direct chemical reaction of the constituent materials during sintering and the result of the chemical reaction with a foreign element. Boron and zirconium carbide system is an example of this type of formation process, which reaction is the result of mixing ZrB_2 plates with rounded ZrCx grains, which ZrCx grains are scattered in the ground under unalloyed conium [19]. In a reaction that contains oxygen in gaseous or solid form, as well as different arrangements of hard compounds, different geometries of particles can be created in the connecting fields. Such systems are Al, ZrN-Zr, TiN-Ti, AlN-Al SiO-. Oxygen can enter the system directly or from an adjacent source such as BaTiO3 or Al_2O_3 contact surfaces [20].

Types of cermet's and their uses

1- Oxide cermet's: This class of materials contains oxide ceramics and metallic components on a microscopic scale. Therefore, it is well placed in the meaning of the word Sarmat. More than most of the mechanical mixtures with the combination of intra-network components and metal phases, oxide cermet's negatively with poor resistance to thermal shock and insufficient fracture toughness, which makes this material useful in many places with high temperatures and dynamic stresses [21-23]. limits, affects. However, some of these materials have good resistance to oxidation or corrosion at high temperatures, and others show unique physical properties such as nuclear fission. In general, oxide cermet's can be produced to withstand high temperature stresses even more than those tolerated by non-metallic oxide ceramics [24-26]. About half of two gins of metal-ceramic oxide cermet's have been produced, some of which have been used in industry [27].

In general, these cermet's differ from alloys that are hardened by oxide dispersion and have a ceramic component that is coarser in importance. Also, in most of these cermet's, the oxide part is significantly more than the materials hardened by oxide dispersion [28].

2- Oxide-silicon cermet's: a classic combination of ceramic and metal can be found in friction metal materials that form the hard phase in these ceramic materials. Industrial machine clamps and long-life brakes, both of which are also found in airplanes, are the largest areas of application for these materials [29].

The ceramic phase is relatively coarse grains of SiO_2, sometimes Al_2O_3 is added to them, and their amount is 2 to 7% of the volume of the material. The metal base consists of brass or bronze and can usually contain iron and lead as well. All materials have some graphite which provides some lubrication.

Conventional P/M techniques such as pressure sintering are used to make friction materials, which are in the form of discs that fit into special connecting cups or plates, or in the form of strips that are directly attached to the protective steel structure [30].

3- Aluminum oxide cermet's: in this type of cermet, ceramic is the dominant phase and metal acts only as an adhesive. Aluminum oxide cermet's are used in cutting cermet's for very fast machining operations with light stock removal. The oxide is ground to a very fine level and then mixed with nickel powder and ground together [31]. Because the adhesive phase rarely exceeds 5-10%, cermet is very brittle after pressing and sintering, and pressure lubrication and organic adhesives are required for ease of operation. Sintering is done in dry hydrogen in dry nitrogen or preferably in a vacuum at a temperature of about 1450 to 1550 degrees Celsius [32].

The termination of the operation is subtle. Another type of aluminum oxide cermet has been used in the past for high temperature and heat resistant applications such as furnace components, jet flame holders, melting vessel mouths, fire protection rods and fasteners. These applications met with only limited commercial success over the years. These cases are made of complex arrangements with a small percentage of TiO_2 in the form of a ceramic phase and by replacing about one fifth of the chromium metal with molybdenum as an adhesive base. However, a similar [33], but less complex arrangement has been used to produce thermocouple protection tubes, which consist of an expanding solid [34].

The tubes are made of double cermet 77% chromium and 23% Al_2O_3. The standard tubular product should have an outer diameter of 22 mm and an inner diameter of 16 mm, which is closed at one end with a length of 910 mm. Other production pipes up to 75 mm diameter and 600 mm length are available everywhere. In making these tubes, the powder mixture is ground to a particle size of about 10 micrometers [35]. Slurry molding, cold pressing and hydrostatic pressing are done at a high sintering temperature of 1560 to 1700 degrees Celsius. The atmosphere of the hydrogen furnace is very pure, which contains controlled amounts of water vapor for surface oxidation of chromium particles. The amount of chromium has a great and important effect on the creep resistance of these cermet's at a temperature of 1380 to 1530 degrees Celsius. With volumes higher than 25% chromium, Al_2O_3 forms an excellent background, and chromium is mainly distributed in a statistically regular phase [36].

For higher chromium concentrations, a network of metal forms that is fully continuous at 50% by volume. Therefore, the superior creep resistance of Al_2O_3 is lost with the formation and completion of the metal network. Many metals were paired with Al_2O_3 in experiments, with the aim of creating a cermet material capable of working at high temperatures and providing acceptable engineering properties [37]. The metals used in this research include nickel, cobalt, iron, molybdenum, tungsten, copper and silver. The main effort was directly to better understand the binding mechanism. However, none of these compounds reached commercial research. Finally, significant materials have been developed in the field of aluminum as the base metal for Al_2O_3 and some fabrication methods, such as solid-state bonding and diffusion reaction, have been used to produce complex and homogeneous features in sheet-like structures. Because aluminum is the dominant phase and Al_2O_3 is used as a reinforcing part, these materials should be classified as metal matrix composite materials [38-40].

4- Magnesium oxide cermet's: Chromium has been used as a metal phase in magnesium-based cermet's. The results of experiments with different metal-ceramic ratios have been reported in scientific articles, in which the amount of magnesium oxide (MgO) varied from 50% by volume to 6% by volume. None of these arrangements have shown properties as favorable as cermet Al_2O_3. However, in the MgO-Cr system [41], an intermediate product of the reaction between metal and ceramic phases was observed. A material containing 6% MgO can be extruded and has an elongation of 10% or more at room temperature and after sintering the extruded powder mixture. The yield and tensile strengths are around 200 and 350 MPa at temperatures up to 600 degrees Celsius, but these strengths decrease at higher temperatures. These resistance properties can remain in higher values of temperature, for example, around 1000 degrees Celsius. If chromium is alloyed with a small amount of niobium. Although this process reduces ductility and malleability, measurable elongation at room temperature was found at 30% chromium by volume, resulting from hydrostatic compression of the coarse powder mixture and sintering at 1600°C. Unfortunately, if this material, which is extremely refractory [42], is subjected to temperatures above 1100-1200 degrees Celsius in the air, it forms nitrides, and this factor causes this cermet to lose its malleability quickly. Nickel, iron, cobalt and alloys of these metals with chromium are used in MgO-based cermet's. In particular, MgO-CO cermet's offer good electrical and mechanical properties in a wide range of configurations [43-45]. For example, the compressive rupture strength at 850°C for 100 hours and for cermet with 50% by weight of cobalt can reach a maximum of 77 MPa. Despite the continuous metal phase of this material, approximately 30% of the volume of this cermet is an insulator. There is no sudden change in resistance like increase or decrease of electrical resistance in the material [46].

5- Beryllium oxide cermet's: according to Resketch, beryllium cermet's that have tungsten connection have better thermal shock resistance and are softer than chrome-alumina materials at higher temperatures. These materials have been successfully used as casting bushes and have also been used for the inlet throat of rocket nozzles. Resketch also considered a combination of beryllium with 50% by volume of beryllium metal for use in high-temperature thermal insulation and winnowing cones for winnowing devices, even though these materials are brittle and toxic [47].

6- Zirconium oxide cermet's: Zirconia is another ceramic that can be bonded to metal to obtain useful refractories, even when with small amounts of metal such as 5 to 15% titanium, it can produce strong and thermal shock resistant materials. These materials are suitable for applications such as casting crucibles for melting rare and reactive metals. If this molybdenum oxide is incorporated, the resulting cermet has excellent corrosion resistance to molten steel, excellent high temperature resistance, and little sensitivity to thermal shock, especially when the metal content is approximately 50% by volume. Its applications include thermocouple coatings for measuring molten metals and extrusion molds used in shaping non-ferrous metals. Zirconium oxide cermet's with a slightly higher amount of ceramic, such as 60% of the volume, are suitable for use in wear-resistant parts [48].

7-Thorium oxide cermet's: Cronin has described metal-ceramic materials that combine very small amounts of thorium with molybdenum or tungsten to create a number of products used in the electronics industry. The main P/M operations performed on metal and oxide powders include screening through 325 mesh, weighing, dry blending, compression, reduced atmosphere sintering, and final machining to define sizes and there are differences. These products take the form of cylinders and covers of a powerful impact magnetron device that can deliver several million watts. They are made in the form of plain discs for use in closed electron discharge tubes, wave return tubes and special purpose guns. In some high-voltage applications, thermionic emission cathodes operate over a wide range of temperatures, but this range is less than that of conventional tube cathodes [49]. Because ThO_2 is present in the refractory metal in a dispersed form as a minor phase of fine particles that rarely exceeds 4-5% by volume, the material in cermet usually exists as a diffuse-type alloy.

8- Uranium oxide cermet's: These cermet's are used in nuclear fuel elements in the reactor core. These materials consist of fissile UO2 dispersed in aluminum, stainless steel or sintered tungsten. In simple terms of oxide fuel, these cermets have better adhesion to fission products and high thermal conductivity that prevents melting at high operating temperatures, usually to ensure that the metal substrate is properly attached and also to limit droplets from the volume. are kept Cermets are stored in stainless steel structures such as pods or molds. Details of the production of uranium oxide cermets by powder metallurgy are given in reference 51. UO_2 may vary in purity depending on its production process and should also be in stoichiometric arrangement. The ceramic particles are relatively coarse and must be strong enough to withstand subsequent work without breaking. The particle size for double crystals is at least 44 micrometers, for single crystals 35 to 44 micrometers and 40 to 50 micrometers for the diameter of very fine grains of irregular crystals. These UO_2 powders are heated at 1600-1700$^{\circ C}$ in hydrogen to increase the particle size, strength and density. A small addition of TiO_2 increases the sintering speed. Processes traditionally used for mixing metal powders and oxides should be reviewed, and finishing point control functions should be used. Because UO_2 radiation is very strong. When there is a large difference between the metal and ceramic densities, intermixing is not sufficient to prevent local concentration and ball milling must be used. Table 5 lists the density and some physical and nuclear properties of UO_2 as well as various background metals in cermet fuels. Standard methods are used for the mixing process of ceramic-metal powder in cermet fuel. With cold pressing, high densities are also achievable when pressure lubrication is also used. Because high temperature sintering is usually not sufficient to achieve the high density and dimensional characteristics of the fuel element, machining is required for sizing and operation. Some disintegrated oxide particles and waste are unavoidable in these cases. Some integrated methods that increase density and reduce breakage, but at the same time increase the production cost, include hot pressing and hot working processes such as extrusion, molding, rolling and drawing. Cermet's containing 50% each of UO_2 and tungsten are used for fuel elements for cold gas reactor cores, which have a cooling temperature of 1500 degrees Celsius and more. This production is carried out by methods such as high-energy compression, hot vacuum or equal pressure compression, powder rolling and extrusion.

9- Cermet's containing other oxides: the development of new technology has increased the demand for new materials with properties compatible with specific applications. An example of these materials is required for cost-effective electronic assemblies as semiconductor components or heat transfer networks. Such materials require a unique combination of thermal and electrical conductivities, sufficient resistance for application, and a controlled thermal expansion coefficient that allows coupling with silicon or any other semiconductor material. Composite materials or special cermets can best meet these needs for a particular system. Because such materials can easily change the properties of metal and ceramic compounds. For example, a composite material including iron and cheruirite

(Al_2O_3 - 2MgO - $5SiO_2$) was produced to achieve a specific and controlled heat coefficient. When the powders were placed in a mold under cold static pressure and then sintered with the addition of 0.2% by volume of E, a full-density cermet was obtained that provided good surface adhesion. By combining up to 40% of the volume of spheroid, the ceramic phase is dispersed in the iron field, which will control the thermal expansion coefficient.

10- High temperature superconductor with metal background: Cermet with another oxide content has also been produced for high temperature superconducting parts. In this cermet, a copper oxide-ceramic mixture is combined with an easily formed metal to produce a composite. Copper is a good choice for the metallic phase. Because it has good resistance, malleability and work-hardening properties, which are combined with its considerable electrical and thermal conductivity. This property makes copper as an outstanding product suitable for the field of ceramic supers or protective cover or both, in order to reduce the force required for forming and making the wire, it is necessary to connect the interface between the ceramic and the metal internally. One way to achieve this goal is to grind YBa_2Cu_3Ox and mesh to very fine powders, mix them well, and then expose the powder to shock waves in one place inside a copper tube.

11- Carbide and carbonitride cermet's: Metal materials bonded to carbide or carbonitride are probably the most important group of cermet's in the present era. From a logical point of view, all metal materials connected to tungsten carbide and titanium carbide fit into the category of cermet's. However, it is common in the industry to refer to all tungsten carbide compounds bonded to cobalt as cemented carbides. This important class of cermet's is discussed in the cemented carbides article in this issue. This section focuses on other categories of metal-bonded carbide or carbonitride materials, such as:

- ✓ Titanium carbide cermet's bonded to nickel with steel.
- ✓ Titanium carbonitride cermet's.
- ✓ Tungsten carbide cermet's bonded to steel.
- ✓ Chrome carbide cermet's.
- ✓ Cermet's based on alkali metals.

12- Theta carbide cermet's semi-connected to nickel: This category of cermet's has attracted a lot of attention in recent years. The development of high-speed turbojet engines for military aircraft, and shortly after the commercial jet transportation, revealed the need for better materials for certain critical locations, especially moving parts in the power supply sector of these types of aircraft. Major efforts have been made to develop TiC cermet's for use in these applications. Important motivations for efforts toward this goal came in the United States and Europe during the 1950s, among them the desirable combination of fine-scale, high-strength, near-good resistance to oxidation at high temperatures, and low specific gravity of phase-phase ceramics. A metal alloy that can give good resistance to thermal and mechanical shock can be named. In these TiC cermet's, the metal phase can be changed in a wide range, which changes from 30 to 72% by weight. The main alloys are Ni-Cr, Ni-Mo-Al, Ni-Mo and Ni-Co-Cr types. Some more complex alloys, such as commercial superalloys, have been used to bond with TiC. Where the resistance of the bonding metal against oxidation at high temperature was not sufficient, such as Ni-Mo, this property in cermet by adding ceramic phases that contain a small amount of carbon and niobium, tantalum or titanium in the solid solution c (Nb, Ta, Ti) with TiC, they were pre-alloyed, increased. Titanium carbide powder is industrially produced from the reaction between TiO_2 and carbon powders as starting materials. Carburization occurs in the presence of gas phase and at reaction temperature of 1600 to 1700 degrees Celsius. The reaction stops only when the carbon content of the product falls below 0.8%. High quality powder has 0.1 to 0.2% free carbon and at least 80.0% titanium. Only two methods are used to make this type of cermet's. The method of producing cemented carbide by conventional method and percolation. The first method, which is still used today, uses co-pressure or uniaxial compaction of metal-ceramic powder mixtures, pre-sintering, shaping by machining, high-pressure vacuum sintering, and finishing operations. By performing this method accurately, especially during the initial processes, very complex shapes can be produced with high accuracy in their dimensions. Air carrier blades with different twists and even turbine rotating parts are completely produced along with single blades whose cover has deep cuts and cemented carbide with this method. If the goal is to obtain compressive strength, high rupture and low creep resistance at the operating temperature of 1000 to 1100 degrees Celsius and it is only from TiC phase, the amount of glue should be low. However, TiC cermet's with low adhesive content are not sufficiently hard. Increasing the amount of metal only slightly improves the hardness and reduces the strength properties of the material. The brittle nature of cemented TiC cermet's affects their performance as turbine blades. Considerable progress has been made to produce an acceptable TiC cermet for this critical turbojet engine performance by increasing the amount of cermet material and simultaneously toughening the binder material by alloying it. The arrangements were different to adapt to the strength and ductility requirements of different parts of the blades, which finally resulted in the use of the percolation process to make the insulation products accepted at the roots and edges and tips of the air-winding blade. The goal of developing serviceable engine components, which are produced with carbide cermet's and by percolation method, was stopped at the same time as the development of metallurgical industries in a small vacuum. Because these industries could produce strong superalloys by deposition method that these superalloys are able to work easily and for long periods at much higher temperatures than gas. However, titanium carbide cermet's have low density and their resistance to high temperature oxidation is better than cobalt cemented tungsten carbide. Therefore, they are still used in various applications with less sensitivity, especially for applications where these characteristics are considered an advantage. Examples of this include fasteners or bolts that operate at high temperatures, plate connections for wear-resistant parts, a nickel-bonded titanium carbide for carbide in sealing rings with 25% Nickel by weight, molybdenum 8% by weight, NbC 6% by weight, WC 3% by weight and the rest is titanium.

Conclusion

Titan carbide cermet's semi bonded to steel:

Titanium carbide cermet's with steel bonding are the result of the rapid development of TiC cermet's with nickel-chromium and cobalt-molybdenum alloy adhesives. This development in the 1950s focused on solving the severe material problems faced in the hot end of jet engines and gas turbines. Efforts to develop new TiC-based cermet's are focused on the broad field of tools and coatings. A new cermet must have major requirements to compete effectively with other material categories in the field of wear-resistant components and durable tools. New sermats are expected to:

- ✓ In annealed conditions, they can be machined with conventional cutting machines.

- ✓ It can be hardened with conventional equipment, without decarburizing and without changing its size.
- ✓ After hardening, they are non-abrasive for difficult applications and perform as well as or better than conventional cemented tungsten carbide.

In general, adding carbide to P/M processes changes the properties of a given steel in a direction that increases hardness, wear resistance, and modulus of elasticity. However, this increase is detrimental to tensile, impact and fatigue properties. The maximum limit for adding TiC is reached when the cermet can no longer be machined or hardened without cracking. The lowest limit cannot be expressed so well. Sintering with the liquid phase occurs when a part with low carbide content loses its shape in the process. The hard phase part in the alloy affects the changes in metallurgical and physical properties, which is according to the law of mixtures.

References

[1] A. Johnson, Eurasian Journal of Chemical, Medicinal and Petroleum Research, **2023**, 2, 1-9. [Google Scholar], [Publisher]

[2] A. Bozorgian, P. KHadiv Parsi, M.A. Mousavian, Iran. J. Chem. Eng., **2009**, 6, 73-86. [Google Scholar], [Publisher]

[3] A. Bozorgian, Journal of Engineering in Industrial Research, **2020** 1 (1), 1-19 [Google Scholar], [Publisher], [Crossref]

[4] A. Bozorgian, B. Raei, Journal of Chemistry Letters, **2020** 1 (4), 143-148 [Google Scholar], [Publisher], [Crossref]

[5] A. Bozorgian, Advanced Journal of Science and Engineering, **2020** 1 (2), 34-39 [Google Scholar], [Publisher], [Crossref]

[6] A. Bozorgian, A. Samimi, Int. J. New Chem., **2021**, 8, 41-58. [Crossref], [Google Schola.r], [Publisher]

[7] A. Ahmadpour, A. Bozorgian, A. Eslamimanesh, A.H. Mohammadi, Desalination Water Treat., **2022**, 249, 297-308. [Crossref], [Google Scholar]

[8] A Samimi, S Zarinabadi, A Bozorgian, Journal of Chemical Reviews, **2020**, 2 (2), 122-129 [Crossref], [Google Scholar], [Publisher]

[9] A Samimi, S Dokhani, N Neshat, B Almasinia, M Setoudeh, International Journal of Advanced Scientific and Technical Research, **2012**, 465-473 [Google Scholar], [Publisher]

[10] A Samimi, M Samimi, Journal of Engineering in Industrial Research, **2021** 2, 1-6 [Crossref], [Google Scholar], [Publisher]

[11] A Samimi, M Samimi, Journal of Engineering in Industrial Research, **2021**, 2 (1), 1-6 [Crossref], [Google Scholar], [Publisher]

[12] A Samimi, Journal of Engineering in Industrial Research, **2021**, 2 (2), 71-76 [Crossref], [Google Scholar], [Publisher]

[13] A Samimi, International Journal of Innovation and Applied Studies,**2012**, 1 (2), 226-231 [Google Scholar], [Publisher]

[14] A Samimi, International Journal of Innovation and Applied Studies, **2012**, 1 (2), 216-225 [Google Scholar], [Publisher]

[15] A Samimi, International Journal of Chemistry, **2013**, 01 [Crossref], [Google Scholar]

[16] A Samimi, International Journal of Basic and Applied science, Indonesia, **2012**, 572-577 [Google Scholar], [Publisher]

[17] A Samimi, International Journal of Basic and Applied science, Indonesia, **2013**, 705-715 [Google Scholar], [Publisher]

[18] A Samimi, B Almasinia, E Nazem, R Rezaei, A Hedayati, M Afkhami, International Journal of science and investigations, **2012**, 1 (10), 49-53 [Google Scholar], [Publisher]

[19] A Johnson, A Brous, A Samimi, Progress in Chemical and Biochemical Res, **2022**,5 (2), 218-228 [Crossref], [Google Scholar], [Publisher]

[20] A Johnson, A Brous, A Samimi, Advanced Journal of Chemistry, Section B, **2022**, 124-134 [Crossref], [Google Scholar], [Publisher]

[21] A. Samimi, S. Zarinabadi, A. Bozorgian, Int. J. New Chem., **2021**, 8, 149-163. [Crossref], [Google Scholar], [Publisher]

[22] B Shakeri, E Heidari, SMA Boutorabi, International Journal of Meta lcasting, **2023**, 1-14 [Crossref], [Google Scholar], [Publisher]

[23] B Shakeri, et al., Inter Metalcast, **2023**. [Crossref], [Google Scholar], [Publisher]

[24] B. Ganavati, V.A. Kukareko, L.S. Tsybul'Skaya, S.S. Perevoznikov, Phys. Metals Metallogr., **2014**, 115, 1037-1045. [Crossref], [Google Scholar], [Publisher]

[25] E Heidari, M Mohammadzadeh, S.M.A. Boutorabi, Inter Metalcast, **2023**, 17, 1637–1649. [Crossref], [Google Scholar], [Publisher]

[26] E Heidari, M Mohammadzadeh, S.M.A. Boutorabi, Inter Metalcast, **2023**, 17, 1637–1649. [Crossref], [Google Scholar], [Publisher]

[27] E Heidari, M Mohammadzadeh, SMA Boutorabi, International Journal of Metalcasting, **2022**, 1-13 [Crossref], [Google Scholar], [Publisher]

[28] E Heidari, SMA Boutorabi, MT Honaramooz, J Campbell, International Journal of Meta lcasting, **2021**, 1-12 [Crossref], [Google Scholar], [Publisher]

[29] E Heidari, Y Esmaeili, S.M.A. Boutorabi, Inter Metalcast, **2023**. [Crossref], [Google Scholar], [Publisher]

[30] E Heidari, Y Esmaeili, SMA Boutorabi, International Journal of Metalcasting, **2023**, 1-11, [Crossref], [Google Scholar], [Publisher]

[31] F Rebout, A Samimi, Progress in Chemical and Biochemical Research, **2022**, 5 (2), 196-217 [Crossref], [Google Scholar], [Publisher]

[32] F. Rebout, Eurasian Journal of Chemical, Medicinal and Petroleum Research, **2022**, 1, 20-32. [Google Scholar], [Publisher], [Crossref]

[33] H Jafari, E Heidari, A Barabi, M Dashti Kheirabadi, Acta Metallurgica Sinica (English Letters), **2018**, 31, 561-574 [Crossref], [Google Scholar], [Publisher]

[34] J. Mashhadizadeh, A. Bozorgian, A. Azimi, Eurasian Chemical Communication, **2020** 2 (4), 536-547 [Google Scholar], [Publisher], [Crossref]

[35] K. Lo Han, Eurasian Journal of Chemical, Medicinal and Petroleum Research, **2022**, 1, 64-70. [Google Scholar], [Publisher]

[36] M Bayanak, S Zarinabadi, K Shahbazi, A Azimi, South African Journal of Chemical Engineering, **2020**, 34, 11-25 [Crossref], [Google Scholar], [Publisher]

[37] M Nikpour, et al., Chinese Chemical Letters, **2010** 21 (4), 501-505 [Crossref], [Google Scholar], [Publisher]

[38] M. Bagheri Sadr, A. Bozorgian, J. Chem. Rev., **2021**, 3, 66-82. [Crossref], [Google Scholar], [Publisher]

[39] M. Zbuzant, Eurasian Journal of Chemical, Medicinal and Petroleum Research, **2022**, 1, 10-19 [Google Scholar], [Publisher], [Crossref]

[40] M. Zbuzant, Eurasian Journal of Chemical, Medicinal and Petroleum Research, **2022**, 1, 40-48 [Google Scholar], [Publisher], [Crossref]

[41] MB Sadr, A Samimi, Advanced Journal of Chemistry, Section B: Natural Products and Medical Chemistry, **2022**, 4, 174-183 [Crossref], [Google Scholar], [Publisher]

[42] N. Norouzi, A.G. Ebadi, A. Bozorgian, E. Vessally, S.J. Hoseyni, Iran. J. Chem. Chem. Eng., **2021**, 40, 1909-1930. [Google Scholar], [Publisher]

[43] T. Mahmut, Eurasian Journal of Chemical, Medicinal and Petroleum

Research, **2022**, 1, 130-137 [Google Scholar], [Publisher], [Crossref]

[44] A Rahimi, A Farhadian, L Guo, E Akbarinezhad, R Sharifi, D Iravani, A Asghar Javidparvar, M A. Deyab, M.A Varfolomeev, Journal of Industrial and Engineering Chemistry, **2023**, 123, 170-186 [Crossref], [Google Scholar], [Publisher]

[45] R Safaeian, R Sharifi, A Dolati, Sh Medhat, South African Journal of Chemical Engineering, **2023**, 45, 51-59 [Crossref], [Google Scholar], [Publisher]

[46] A Farhadiana, A Mohammadi, M Maddahd, E Sadeh, R Nowruzi, R Sharifi, Z Taheri Rizi, M Mohammad Taheri, Y Seo, SSRN, **2023**, [Crossref], [Google Scholar], [Publisher]

[47] R Sharifi, S Soroushian, M Ehteshamzadeh, Fourteenth student scientific conference on Iranian Materials and metallurgical engineering, The 14th scientific conference of students of material engineering and metallurgy of Iran, **2017**, [Crossref], [Google Scholar], [Publisher]