This is a postprint version of the following published document:

Alvaredo, P., Dios, M., Ferrari, B., & Gordo, E.
(2019). Understanding of wetting and solubility
behavior of fe binder on ti(C,N) cermets. Journal of
Alloys and Compounds, 770, 17-25.

doi:<https://doi.org/10.1016/j.jallcom.2018.07.243>

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Understanding of wetting and solubility behavior of Fe binder on Ti(C,N)-based cermets

P. Alvaredo^{1*}, M. Dios^{1,2}, B. Ferrari², E. Gordo¹

¹Department of Materials Science and Engineering, IAAB. University Carlos III of Madrid, Avda. Universidad, 30, 28911 Leganés, Madrid, Spain *paula.alvaredo@uc3m.es

²Institute of Ceramic and Glass, CSIC, c/Kelsen 5, 28049 Madrid, Spain

Abstract

Given the great interest generated in the last years by the searching of new binders in hard materials, a work methodology has been created that allows the design of new metal – ceramic combinations. It includes the study of the solubility between the new binder and the reinforcement during the design of the binder composition combined with the knowledge of the sintering behavior of the cermet by monitoring the contact angle of the liquid phase formed at high temperature.

Iron is considered as the main alternative binder in cermets; however proper compositions are still under development as it is necessary to improve the sintering. This work propose the use of Ni as sintering aid to improve the wettability without the introduction of secondary phases. The article shows a comprehensive study of the high temperature behavior, in terms of solubility and wettability, of the system FeNi/Ti(C,N) , and the results are compared with the study of the conventional system Ni/Ti(C,N). A better understanding of the high temperature behavior between binder and reinforcement allows to design new compositions and to search strategies to improve the densification of the cermets.

1. Introduction

Ti(C,N) cermets are gaining increasing technical importance due to their excellent and unique combination of physical properties such as high melting point, hardness, thermal conductivity, wear resistance and good chemical and thermal stability [1]. Traditionally, in the production of cermets, the starting materials are typically TiC or Ti(C,N) as ceramic phase. Other secondary

carbides of refractory metals such as WC, TaC, NiB, Cr₂C₃, VC and Mo₂C are frequently added to improve the sinterability [2], or specific properties such as thermal shock resistance, chemical stability as well as hinder the ceramic particle growth [3, 4]. The binder phase or metal matrix is usually composed by Ni, Co, or a combination of both. Nevertheless, in an attempt to replace the metal matrix with less toxic and cheaper elements, while maintaining the mechanical properties, iron based binder emerges as a competitive alternative in spite of the inconvenience in terms of wettability. Apart from that, TiN additions have been found useful for the processing of TiC-based cermets due to its grain growth inhibitor effect improving the resistance to high-temperature creep deformation [5, 6].

In order to evaluate the feasibility of a particular metal as an alternative binder, it must be taken into account that these composite materials are processed through liquid phase sintering (LPS). So, to favor the grain rearrangement and final densification, the binder should melt during sintering and the ceramic phase should be at least slightly soluble in the binder liquid phase. Moreover, as the metal melts, impregnation of the liquid phase in the solid porous structure will be promoted. That means the infiltration by capillarity of the metal governs the first sintering step in terms of wettability and dissolution of the ceramic phase. Further steps of sintering involve the precipitation of the metal phase bridging ceramic grains. At this point, the dissolutive character of the liquid binder on the ceramic particles is also a determining factor in the success of the process [7].

Both concepts, wettability and solubility, are closely related. The determination of the wetting behaviour will depend only on the initial physicochemical characteristics of liquid and solid only in the case of static systems in which there is no dissolution or reaction between liquid and solid (inert system). However, the study of dynamic systems (reactive or dissolutive) is more complex because the wettability will depend on the new phase formed at the interface or the changes in the composition of the liquid and solid caused by the dissolution of the solid and further re-precipitation.

It is well known that during liquid-phase sintering, ceramic particles in cermets produce a unique “core-rim” microstructure via dissolution-reprecipitation mechanisms. Normally, the composition of the core in Ti(C,N)-based cermets, namely the hard phase, is believed to be undissolved nitrogen-rich Ti(C,N) nuclei due to the higher solubility of TiC in the liquid metal compared to the

low solubility of TiN [8]. The rim is a solid solution (Ti, W, ...)(C,N), which has a similar crystalline structure than the core but with higher concentration of heavy atoms such as W, Mo, V, Ta, Nb, etc. depending of the secondary carbide added to the cermet [9-11]. This work studies the addition of Ni as sintering aid instead of adding secondary carbides, in an attempt to avoid the harmful effects of brittle phases formed at the rim.

In previous works, the suitability of using diffusion couples have been tested to measure diffusivities for the field of transition metal carbides and nitrides [12-14]. However, difficulties connected with the concentration measurement at the interfaces and problems associated with the formation of quasi-equilibrated diffusion zones leads to search for new and more accurate alternative techniques [15]. The present work details a systematic study to obtain a better knowledge of the LPS mechanism in Ti(C,N)-based cermets with different binders (Fe, Ni and Fe-Ni) with the aim to determine which are the characteristics which have to fulfil in these metal-ceramic materials to achieve a good densification to tailor and to design new binder compositions. For this purpose, a combination of simulation tools and experimental tests is used. High temperature wetting experiments are performed to observe the evolution of contact angle between liquid metal and ceramic substrate from the formation of the liquid phase. The study of the interface formed after the wetting experiments combined with thermodynamic and kinetic simulations by ThermoCalc and Dictra software will allow the understanding of the main interaction mechanisms. These analyses will help to explain the sintering behaviour of the cermets, and to establish a systematic way for searching new compositions.

2. Experimental procedure

The powders used as starting materials in this work were: Ti(C,N) (grade C, H. C. Starck, Germany; D50 = 2.0 – 4.0 μm), TiC (H. C. Starck, Germany; D50 = 1.0 μm), TiN (H. C. Starck, Germany; D50 = 1.0 μm), Fe (H. C. Starck, D50 = 3.5 μm), Prealloyed Fe-15Ni (H. C. Starck, Germany, D50 = 3.5 μm) and Ni (INCO T-110; D50 = 1.7 μm). And the metal/ceramic systems studied in this work are formed by Fe, Ni and Fe-15 wt. %Ni alloy as metallic phases and TiC, TiN and Ti(C,N) as ceramic phases.

The simulation of high temperature solubility at the interface between the liquid metal sample (Fe, Ni or Fe-15Ni) and solid ceramic substrate (TiC, TiN or Ti(C,N)) was performed by using the software Dictra with TCFE7 and TTNi7 databases. The design of the system used in the simulation is schematically shown in Figure 1. The interface thickness considered for simulations was 1000 μm , where two regions were defined, the left one (500 μm thick) corresponds with the liquid metal region and the right one (500 μm thick) corresponds with the solid ceramic substrate. The temperature of simulations was chosen in order to maintain metals in liquid state. Consequently, the temperature for the simulation of the Ni/Substrate system was 1500 °C because the theoretical melting point of the Ni is 1455 °C, whereas for the Fe/Substrate system was 1550 °C because the theoretical melting point of the Fe is 1538 °C.

Figure 1. Scheme of the system designed for the simulation of the diffusion at the interface between the liquid metal sample and the solid ceramic substrate.

The equilibrium phase diagrams shown in this work were calculated using the ThermoCalc software [16]. Calculations are based on the free Gibbs energy minimization code and mass conversion rule, in combination with TCFE7 and TTNi7 databases (Scientific Group Thermodata Europe).

To study the wetting behavior of metals on ceramic substrates wetting experiments at 1500 °C and 1550 °C for Ni and Fe respectively, were performed. These experiments were conducted in a tube furnace under Ar atmosphere. The furnace is provided with a camera to record the metal melting and the formation of the liquid metal drop as well as its evolution with time. So, the evolution of the contact angle between the two phases with respect to the residence time and temperature was monitored by the sessile drop method, taking as $t = 0$ the moment at which the melting of the metal sample is started. For these tests, the metallic samples were prepared by a conventional powder metallurgy route (uniaxial pressing and vacuum sintering at 1450°C for 1 hour) to obtain homogeneous metals and alloys to place onto the ceramic substrates; the ceramic samples (Ti(C,N), TiC and TiN substrates) were sintered by Spark Plasma Sintering (DR. SINTER SPS-1050-CE Fuji Electronic Industrial, Japan) at 1900 °C and 70 MPa with a heating and cooling rate of 100 °C/min achieving relative densities of 99.5 %, 96.0 % and 98.3 %, respectively.

After the wetting experiments, cross sections of the metal/ceramic interface were prepared by a conventional metallographic route with a final polishing step of 1 μm diamond suspension and observed by Scanning Electron Microscope (XL-30 Scanning Electron Microscope Philips, Netherlands) and analyzed by EDX.

3. Results

3.1. *High temperature behavior of Fe, Fe-15Ni and Ni on Ti(C,N)*

To study the wetting behavior of the metals Fe and Ni and the alloy Fe-15Ni on a Ti(C,N) substrate high temperature wetting experiments have been performed. Figure 2 shows the evolution of the contact angle of metallic samples on the ceramic substrate Ti(C,N) with respect to the residence time; the beginning of the liquid phase formation, that is, the starting the melting of metallic sample, evidenced by a change in the shape of the sample, has been taken as $t=0$. The contact angle of the liquid Fe displays a different evolution ~~than those~~ of the Ni-contained compositions. From the beginning of the Fe sample melting the contact angle is higher than 90° and it remains constant until 550 s of residence time when it decreases sharply down to 64°. The behavior of the contact angle evolution of the Ni containing samples is quite different: since the liquid phase formation the contact angle of the liquid Ni and Fe-15Ni on Ti(C,N) substrate is

lower than 90° (65° and 80° respectively), and decreases smoothly with the residence time to achieve a final contact angle of 10° and 24° respectively, highlighting the better wettability of these metallic phases on Ti(C,N) substrates.

The SEM images of the cross section of the three metallic sample/ Ti(C,N) interfaces after the wetting experiments show that the three systems have a dissolutive character although the presence of Ni enhance this behaviour. Both liquid Ni and Fe-15Ni dissolve the grain boundaries of the Ti(C,N) substrate and infiltrate in the substrate for thickness higher than $100\text{ }\mu\text{m}$, while this effect in the interface Fe/Ti(C,N) is limited to $10\text{ }\mu\text{m}$ from the surface of the substrate.

Figure 2. a) Evolution of the contact angle of the liquid Fe, Ni and Fe-15Ni in contact with Ti(C,N) substrate with the residence time; b) camera shots of the evolution of liquid drop with time and c) micrographs of the interface of the systems Fe/Ti(C,N), Fe-15Ni/Ti(C,N) and Ni/Ti(C,N) after high temperature wetting experiments

The difference found in the high temperature wetting behavior of liquid Fe on Ti(C,N) and liquids containing Ni (pure Ni and Fe-15Ni) on Ti(C,N) could be related with their different dissolutive character. The calculation of the pseudobinary phase diagrams is useful to study such differences. Figure 3 a and b shows the diagrams for Fe/Ti(C,N) and Ni/Ti(C,N) systems showing the lines which determine the solubility of Ti(C,N) on both liquid metals, and its dependence with the temperature. They confirm the higher solubility of Ti(C,N) in liquid Ni which is the cause of the wider interface developed in this system shown in Figure 2. Furthermore, in the Ni/Ti(C,N) pseudobinary phase diagram the increase of the solubility of Ti(C,N) in liquid Ni provokes the emergence of a region in which Ni, Ti(C,N) and liquid phase coexist. Moreover the dissolution of Ti(C,N) results in a decrease of the solidus temperature of Ni.

On the other hand the Fe/Ti(C,N) pseudobinary phase diagram shows a narrow region in which Fe, Ti(C,N) and liquid phase coexist and the solidus temperature of Fe remains constant with the presence of Ti(C,N). Differences of Ti(C,N) solubility in the liquid metals are related to their different wetting behavior.

Figure 3. Calculated pseudobinary phase diagrams of a) Fe/Ti(C,N) and b) Ni- Ti(C,N).

The differences on the solubility of Ti(C,N) in Fe and Ni also are reflected in the displacement position of interfaces Fe/Ti(C,N) and Ni/Ti(C,N). That displacement has been simulated using DICTRA software and it is shown in Figure 4a. The position of the interface Ni/Ti(C,N) changes at early time of residence while the position of the interface Fe/Ti(C,N) is displaced at higher residence time. Also, the higher displacement of the interface Ni/Ti(C,N) position than Fe/Ti(C,N) is clearly observed in the interfaces after wetting experiments shown in Figure 4b.

Figure 4. (a) Simulation of the displacement of the interface position formed in the systems Fe/Ti(C,N) and Ni/Ti(C,N) and (b) SEM images of interphases metal-ceramic after wetting experiments.

Taking into account these results it seems clear that an increase in the solubility of Ti(C,N) on the liquid metal improve the wetting behavior of the liquid metal on the Ti(C,N) substrate. In order to have a deeper understanding of the high temperature behavior of the Fe sample on Ti(C,N) substrate, the interface formed between them has been studied at two residence times, 300 s and 600 s. After 300 seconds, the liquid metal does not wet the ceramic substrate, and a third phase appears as a layer between metal and Ti(C,N). The composition of this layer (EDX analyses in Table 1) shows that is formed by substoichiometric TiN, probably due to the diffusion of C to liquid Fe. After a residence time of 600 seconds when the liquid metal wets the substrate, the interface analysis shows the dissolution of the layer of substoichiometric TiN by the liquid Fe, which could be the responsible of the contact angle decrease at higher residence time.

Figure 5. Interface between Fe and Ti(C,N) after wetting experiments performed during 300 s and 600 s.

Table 1. Composition (EDX analysis) of Fe metal phase, interface and Ti(C,N) after wetting experiment performed during 300 s

The evolution of the diffusion of C, N, Ti and Fe between liquid Fe and Ti(C,N) with respect residence time has been studied by kinetic simulation. Figure 6 shows the evolution of the amount of each element in a distance of 100 μm around the interface (distance = 0 μm) during 1, 10, 100 and 1000 s at 1550 $^{\circ}\text{C}$. The results obtained by simulation are in agreement with the previous analysis performed at the interface after wetting experiments. It is observed that the

diffusion of liquid Fe into the substrate of Ti(C,N) is negligible, while the diffusion of C is the most pronounced. In the case of Ti and N, diffusion is also observed but the highest percentages of these elements are found in the vicinity of the interface. This preferential dissolution of TiC by liquid Fe leaving behind a nitrogen-rich carbonitride is quite similar to the behavior of Ni on Ti(C,N) studied by W. Lengauer [13] and it is also observed in the results obtained by the simulation of the diffusion of the elements C, N, Ti and Ni in the interphase liquid Ni/Ti(C,N) showed in Figure 7. In these graphics can also be observed the decreasing of the C percentage at the surface of the solid Ti(C,N) while the N increases its percentage with time. However due to the higher solubility of Ti(C,N) in liquid Ni than in liquid Fe, the diffusion of the elements is more evident.

Figure 6. Diffusion of C (wt. %), N (wt. %), Fe (wt. %) and Ti (wt. %) at the metal-ceramic interface of Fe/Ti(C,N) system simulated by Dictra software.

Figure 7. Diffusion of C (wt. %), N (wt. %), Ni (wt. %) and Ti (wt. %) at the metal-ceramic interface of Ni/Ti(C,N) system simulated by Dictra software.

Another evidence of the dissolution of Ti(C,N) in different liquid metals is the temperature of liquid phase formation. During the wetting experiments, the temperatures at which liquid phases appear are registered and, comparing those with the theoretical melting point of Fe, Ni and Fe-15Ni (Table 2) there is a decreasing of the melting temperature of the samples with Ni while the sample of Fe melts at a temperature quite close than its theoretical melting point. This decreasing in the temperature of the liquid phase formation in the samples with higher solubility of Ti(C,N) is due to the presence of C, that due to dissolution from Ti(C,N) decreases the liquidus temperature of the metal phase as can be observed in Figure 8. In these phase diagrams the evolution of Ni and Fe-15Ni is represented with respect the carbon content. It is clear that an increase in the C content decrease the liquidus temperature in both metals, so the presence of C from the Ti(C,N) substrate is the responsible of the temperature of liquid phase formation.

Table 2. Melting point and temperature of liquid phase formation of Fe, Fe-15Ni and Ni.

Figure 8. Phase diagram of Ni-C (a) and (Fe-15Ni)-C (b).

3.2. High temperature behavior of liquid Fe and liquid Ni on TiC and TiN.

From the previous results, it is possible to conclude that there is a different behavior of the liquid metals, Fe and Ni, on TiC or TiN, therefore a deeper study of the high temperature behavior of liquid Ni and liquid Fe on these two substrates is carried out by wetting experiments and phase diagrams calculations.

Figure 9 shows the wetting behavior of liquid Ni on TiC and TiN substrates and the interfaces formed between both phases after the wetting experiments, which were performed maintaining 1500°C for 600 s in Ar atmosphere. Figure 9a) shows the evolution of the contact angle of liquid Ni on TiC and TiN substrates with time, as well as the micrographs showing the evolution with time of the liquid Ni drop. Liquid Ni shows contact angles lower than 90° on both TiN and TiC substrates, although results evidence differences in the wetting behavior of both systems: the contact angle of liquid Ni on TiC substrates fall to 30 ° in 200 s and decrease to 25° at the end of the experiment (600 s) whereas in the TiN substrate the final contact angle is 55° and decreases less from the initial value. A detailed microstructural study of the interfaces (Figure 9b) and d)) evidences the main difference is the ability of liquid Ni to dissolve the TiC phase. In fact, SEM images show how Ni and TiC form a dissolutive system (Figure 9 b)) and Ni and TiN form an inert system (Figure 9 d)). The Ni/TiC system exhibits a wide interface area of 50-70 µm thick where ceramic grains are dispersed in a Ni matrix. Other evidences of the dissolution of TiC on liquid Ni are shown in the detail of the Ni microstructure after the solidification of the drop (Figure 9 c)), where the precipitation of TiC can be observed within the Ni phase. Contrarily, the clear and straight interface between Ni and TiN in Figure 9 d) is typical of an inert system where the dissolution between compositions is null. Differences between the solubility of TiC and TiN in liquid Ni confirm the results previously described in the literature [12, 13].

Figure 9. a) Evolution of the contact angle of Ni on TiC and TiN substrates. b) Interface of the Ni/TiN system after wetting experiment c) Detail of Ni sample after Ni/TiN wetting experiment. d) Interface of the Ni/TiC system after wetting experiment. e) Detail of Ni sample after Ni/TiC wetting experiment.

Consequently, it is noteworthy that the wetting behavior of the system Ni/TiC will be determined by the solubility of the substrate in the liquid metal, whereas the wetting behavior of the system

Ni/TiN will be only ascribed to the physicochemical properties of the liquid metal and ceramic particle due to the negligible solubility of TiN in liquid Ni.

The different solubility of both systems is also appreciated in the pseudobinary phase diagrams Ni/TiC and Ni/TiN shown in Figure 10 in which the evolution of solubility of TiC and TiN in Ni with respect temperature is represented by dotted lines. Besides, the Ni/TiC pseudobinary phase diagram shows an eutectic point at 1270 °C which can be the responsible of the microstructure of the Figure 9c.

Figure 10. Pseudobinary phase diagram of a) Ni/TiC and b) Ni/TiN.

The high temperature wetting behavior of liquid Fe on TiC and TiN is similar to liquid Ni but much more pronounced due to the higher difference on the solubility of the systems liquid Fe/TiC and liquid Fe/TiN, which are represented in the pseudobinary phase diagrams of Figure 11. The dotted lines indicate the evolution of the solubility of TiC and TiN in liquid Fe with the temperature, highlighting the higher solubility of TiC than TiN in liquid Fe. Furthermore the system Fe/TiC exhibits an eutectic point at 2.5 wt. % TiC decreasing the solidus temperature down to 1480 °C.

Figure 12a) shows the evolution of the contact angle with time of liquid Fe on TiN and TiC substrates calculated in wetting experiments performed at 1550 °C during 600 s. In both systems, the liquid Fe forms a contact angle higher than 90°. However, it decreases dramatically at the beginning of the experiment for Fe/TiC while maintains constant for the system Fe/TiN. The decrease of the contact angle to a value almost zero could be due to the high solubility of TiC in Fe as the Fe/TiC pseudobinary phase diagram in Figure 11 shows. In fact, the temperature of the wetting test exceeds the temperature of the eutectic point (1480 °C), and the interface formed by a mixture of phases can be clearly observed in Figure 12b). In this system, the thickness of the interface ranges from 100 to 200 µm and it is formed by two regions proving that Fe dissolves the TiC substrate and infiltrates through the grain boundaries of TiC forming a composite. In fact, at the interface, it can be further appreciated the formation of perlite in the Fe microstructure (detail in Figure 12d)).

In the case of Fe/TiN system the wetting behavior it is completely different, liquid Fe forms a contact angle higher than 90° with the TiN substrate during the experiment. The poor wettability of liquid Fe on TiN leads to a poor adhesion of both phases (Figure 12c)), proving that Fe/TiN forms an inert system, and the wetting behavior will only depend on their physicochemical properties.

Figure 11. Pseudobinary phase diagram of a) Fe/TiC and b) Fe/TiN.

Figure 12. a) Contact angle evolution of liquid Fe on TiC and TiN substrates. b) Interface of Fe/TiC after wetting experiment. c) Interface of Fe/TiN after wetting experiment. d) Detail of the interface between Fe/TiC.

It can be concluded that the high temperature behavior of Fe on Ti(C,N) is a synergy between the high temperature behavior of Fe on TiC and TiN as it can be clearly observed in Figure 13. In this figure, it is shown the results of the simulation of the interface displacement of systems Fe/Ti(C,N); Fe/TiC and Fe/TiN at high temperature. It is observed a great displacement of the Fe/TiC interface due to the high solubility of TiC in Fe, the small displacement of the Fe/TiN interface and the intermediate displacement of the Fe/Ti(C,N) interface position. This intermediate behavior is due to the initial dissolution of TiC which leaves a substoichiometric TiN layer which is not wetted by liquid Fe. Once the substoichiometric layer of TiN is dissolved the liquid Fe wets the Ti(C,N) substrate. Ergo, as in the case of conventional matrix cermets with Ni binders, in cermets with alternative Fe matrix the final properties of the compound material will be very sensitive to the reinforcement stoichiometry, TiC_xN_y , [17-19] since a higher C/N ratio on the reinforcement will improve the solubility and wettability of the liquid binder on the reinforcement during the sintering and, therefore, in its microstructure and properties.

Figure 13. Simulation of the displacement of the interface position with time in the systems Fe/TiC; Fe/TiN and Fe/Ti(C,N).

4. Conclusions

In this study it is proposed a working methodology to search and design new metallic binders in hard materials, cemented carbides and cermets. First, the design of compositions using thermodynamic and kinetic simulation tools help [to](#) study the solubility between binder and

reinforcement. Subsequently the study of the evolution of wetting behavior at high temperature allows the understanding of the sintering behavior.

In view of the results obtained, it can be concluded that the high temperature wetting behavior of Fe on Ti(C,N) is a synergy between the behavior of Fe on TiC which shows a highly dissolving character and the behavior of Fe on TiN which form an inert system with zero solubility and wettability. Thus the wetting of Ti(C,N) by a liquid Fe sample is not instantaneous because it is the result of two completely different high temperature behaviors. The wetting behavior of Fe on Ti(C,N) is clearly improved by the addition of a small quantity of Ni because it increases the solubility of Ti(C,N) on the liquid metal.

The wetting of Ni on Ti(C,N) is instantaneous and more effective because both systems, Ni/TiC and Ni/TiN show good wetting behavior. It should be noted that, in contrast to what happens with the Fe/TiN system, the Ni/TiN system, which is also inert, has a lower contact angle.

So it can be concluded that the low wettability of Fe on TiN is the responsible of the poor sintering of Fe binder cermets reinforced with Ti(C,N).

Nevertheless, in view of the results obtained the addition of small amount of Ni (15 wt. %) to the Fe binder reduces the contact angle of the liquid phase to values close to the Ni ones, which opens the possibility of replace Ni as binder avoiding the addition of secondary carbides as Mo₂C or WC used conventionally to improve the sintering of cermets.

Acknowledgements

The authors would like to acknowledge the financial support from the Spanish Government through the project MAT2015-70780-C4-2-P, MAT2015-70780-C4-1-P, and the Regional Government of Madrid through the program MULTIMAT-CHALLENGE, ref. S2013/MIT-2862.

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Solubility Sintering Wetting

- The design new binder composition needs a better understanding of the high temperature behavior between binder and reinforcement.
- High temperature behavior is determined by solubility and wetting behavior.
- The poor sintering of Fe binder cermets reinforced with Ti(C,N) is due to the low wettability between Fe and TiN.
- A small addition of Ni to Fe binder improves the wetting behavior on Ti(C,N) substantially.
- The improving in the wetting behavior of Fe opens the possibility of replace Ni as binder avoiding the carbides addition.

Table 1. Composition (EDX analysis) of Fe metal phase, interface and Ti(C,N) after wetting experiment performed during 300 s

(% at.)	Fe	Ti	N	C
Fe phase	90,2	1,1	2,6	6,1
Interface	2,4	72,3	22,9	2,4
Substrate	0,6	55,7	21,6	22,3

Table 2. Melting point and temperature of liquid phase formation of Fe, Fe-15Ni and Ni.

	Fe	Fe-15Ni	Ni
Melting point (°C)	1538	1498	1455
Liquid phase formation (°C)	1542	1478	1380

Figure

Figure 1. Scheme of the system designed for the simulation of the diffusion at the interface between the liquid metal sample and the solid ceramic substrate.

Figure 2. a) Evolution of the contact angle of the liquid Fe, Ni and Fe-15Ni in contact with Ti(C,N) substrate with the residence time; b) camera shots of the evolution of liquid drop with time and c) micrographs of the interface of the systems Fe/Ti(C,N), Fe-15Ni/Ti(C,N) and Ni/Ti(C,N) after high temperature wetting experiments

Figure 3. Calculated pseudobinary phase diagrams of a) Fe-Ti(C,N) and b) Ni- Ti(C,N).

Figure 4. (a) Simulation of the displacement of the interface position formed in the systems Fe/Ti(C,N) and Ni/Ti(C,N) and (b) SEM images of interphases metal-ceramic after wetting experiments.

Figure 5. Interface between Fe and Ti(C,N) after wetting experiments performed during 300 s and 600 s.

Figure 6. Diffusion of C (wt. %), N (wt. %), Fe (wt. %) and Ti (wt. %) at the metal-ceramic interface of Fe-Ti(C,N) system simulated by Dictra software.

Figure 7. Diffusion of C (wt. %), N (wt. %), Ni (wt. %) and Ti (wt. %) at the metal-ceramic interface of Ni-Ti(C,N) system simulated by Dictra software.

Figure 8. Phase diagram of Ni-C (a) and (Fe-15Ni)-C (b).

Figure 9. a) Evolution of the contact angle of Ni on TiC and TiN substrates. b) Interface of the Ni/TiN system after wetting experiment c) Detail of Ni sample after Ni/TiN wetting experiment. d) Interface of the Ni/TiC system after wetting experiment. e) Detail of Ni sample after Ni/TiC wetting experiment.

Figure 10. Pseudobinary phase diagram of a) Ni-TiC and b) Ni-TiN.

Figure 11. Pseudobinary phase diagram of a) Fe-TiC and b) Fe-TiN.

Figure 12. a) Contact angle evolution of liquid Fe on TiC and TiN substrates. b) Interface of Fe/TiC after wetting experiment. c) Interface of Fe/TiN after wetting experiment. d) Detail of the interface between Fe/TiC.

Figure 13. Simulation of the displacement of the interface position with time in the systems Fe/TiC; Fe/TiN and Fe/Ti(C,N).