Effect of a Titanium Nitride Interlayer on the Densification, Properties and Microstructure of Cermets Based on Alumina and Nickel — Part 1: Densification and Properties

Shujie Li, Paul Babayan Khosrovabadi & Ben H. Kolster
Foundation for Advanced Metals Science, Department of Mechanical Engineering, University of Twente, PO Box 217, 7500 AE Enschede, The Netherlands
(Received 15 June 1992; accepted 26 October 1992)

Abstract: In order to manufacture cermets based on Al₂O₃ and Ni, Al₂O₃ particles were first coated with TiN by CVD and then mixed with pure Ni powder. The cermets were produced from the mixed powders by powder metallurgy processes. The relative density and the mechanical properties of the cermets are improved due to the presence of the TiN interlayer. The contribution of this interlayer to the mechanical properties of the cermets produced by hot-pressing is superior to that by pressureless sintering.

1 INTRODUCTION

Different kinds of cermets are widely employed in industry due to their favourable properties which are different from those of ceramics and metallic materials. As one of their representatives, the cermet composed of WC and Co has been used as a wear-resistant material for several decades. However, this cermet is expensive because both tungsten and cobalt are not abundant materials. Furthermore, the high specific gravity of this material makes the parts too heavy to use in some cases. Hence, during the last 30 years many attempts have been made to find alternative cermets with relatively comparable properties coupled with favourable cost.¹⁻⁹ Although much significant progress has been reported,¹⁻⁹ the cermet composed of WC and Co has not been replaced in industry so far.

The aim of this study is to develop and evaluate a new and cheaper cermet with combined favourable mechanical properties such as hardness, strength and toughness as well as relatively lower specific gravity for wear-resistant applications. For this purpose, Al₂O₃ and Ni were selected as the starting materials due to their favourable properties and easy availability. However, the problem associated with these two components is the poor wettability between solid Al₂O₃ and liquid Ni,¹⁰ which hinders the manufacturing of this cermet by liquid phase sintering. In order to improve the sintering ability of this material, attention was focused on introducing interlayers which would contribute to a better adhesion between the ceramic phase and the metallic phase. The introduction of interlayers was effected by coating the Al₂O₃ powder with different kinds of materials preceding the powder metallurgy process. In this study, different interlayers such as pure Ni, Ni(P), Co(P), CoMo, TiOₓ, and TiN were tested. (Ni(P) indicates that the interlayer consists mostly of Ni with a very low content of P). Among these interlayers, TiN was found to be the best suited to achieve this goal. It will be seen in this paper that the sintering ability of the material at solid state condition is improved significantly by
incorporating this interlayer, and consequently, the mechanical properties are improved pronouncedly. Since the chamber of the employed hot-pressing machine is not large enough to manufacture samples for tensile and bending tests, only compressive tests to determine mechanical properties have been conducted in this study.

2 EXPERIMENTAL PROCEDURES AND CHARACTERIZATION OF THE POWDERS

Pure Al₂O₃ powder with a particle size of 40–50 μm was selected as one of the starting materials. The density of the powder was determined by the Archimedes liquid-displacement technique. The liquid used was diethyl phthalate. The density of the powder was found to be $3.957 \pm 0.001 \times 10^3$ kg/m³.

The Al₂O₃ powder was then coated with TiN by CVD. (This powder was obtained from Xycarb, one of the partners of the Brite-Euram project 'Sintering of Coated Ceramic Powders for Wear and Fatigue Resistant Components', Dutch patent No. 9 000 346.) The Al₂O₃–TiN powder (in this paper, Al₂O₃–TiN represents Al₂O₃ powder coated with TiN) was characterized by SEM and EDX. Figure 1 shows scanning electron micrographs of the powder. The corresponding ED spectra are shown in Figures 2 and 3. These figures indicate that the shape of the powder is irregular and that the surface of the Al₂O₃ powder is almost completely coated with the TiN layer. Figure 4 shows another scanning electron micrograph of the same batch of the Al₂O₃–TiN powder. Figure 5 shows the EDX spectrum analyzed at area 2 in Fig. 4. The spectrum analyzed at area 1 in this figure is similar to Fig. 5 and is omitted in this paper. These figures indicate that the analyzed area 2 of the particle is not coated. Figure 6 shows other scanning electron micrographs of the powder. This figure reveals that there are holes in the coating layer of the powder.

A large number of particles (over 100) were analyzed and it was found that the uncoated area is very limited (below about 3%). The Ti content of the powder was analyzed by X-ray fluorescence spectrometry and was found to be 4.09 wt %. Consequently, the TiN content of the powder was calculated to be 5.29 wt %. The density of the Al₂O₃–TiN powder was determined by the aforementioned liquid displacement technique to be $4.013 \pm 0.001 \times 10^3$ kg/m³.

Since the shape of the powder is irregular, it is difficult to calculate accurately the thickness of the coating layer. It is possible, however, to estimate the thickness by assuming that the shape of the powder is regular, e.g. spherical, and that the thickness of coating for the powder is homogeneous. Based on these assumptions, the thickness of the coating layer was estimated to be about 0.3 μm. In a following paper, the thickness of the coating layer can be seen from the microstructure of the cermets, showing that it is comparable with this value.

Fig. 1. Scanning electron micrographs of Al₂O₃–TiN powder. Micrograph (A) shows the shape and size of the powder, whilst (B) reveals the coated surface of a particle. The white particles on the surface are small TiN granules (cf. Fig. 3).
Pure Ni powder (99.9%) was selected as the other starting material used as the metallic constituent of the cermet. The particle size of the Ni powder was 1-3 μm.

The Al₂O₃-TiN powder together with Ni powder at a volume ratio of 48.9:51.1 (the value of the volume ratio was calculated based on the value of weight ratio and full densification) were mixed for 45 min in a cylindrical mixer with alumina balls. Then the mixture was compacted at room temperature and 749 MPa for 60 s. The weight of each sample was 6.5 g. The compacts were pressureless sintered in a tube furnace in a vacuum of $7 \times 10^{-2}$-7 $\times 10^{-4}$ Pa ($5 \times 10^{-4}$-
5 \times 10^{-6} \ \text{torr}) \ for \ 1 \ \text{h} \ at \ 1150, \ 1250 \ \text{and} \ 1350^\circ \text{C}, \ \text{respectively.}

Cold-compacted samples of 8 g each were also hot-pressed at 41 MPa for 1 h at 1150 and 1200°C, respectively, by employing a thermo-mechanical testing machine, made by Duffers Scientific Inc. (USA), type Gleeble 1500, with graphite dies in a vacuum of $7 \times 10^{-3} - 7 \times 10^{-4}$ torr.)

Fig. 4. Scanning electron micrograph of Al$_2$O$_3$-TiN powder. It shows the uncoated area of the surface of a particle. (The background is carbon glue to hold the particles).

Fig. 6. Scanning electron micrographs of Al$_2$O$_3$-TiN powder. Micrograph (A) shows a hole in the coating layer, whilst (B) shows the same hole as above at larger magnification.

Fig. 5. EDX spectrum analyzed at area 2 as indicated by the arrow in Fig. 4.
Pa \((5 \times 10^{-5} - 5 \times 10^{-6}\) torr). An isolating layer (called 'stop off', composed of titanium oxide and diluent) was used between the sample and the graphite dies to prevent them from interacting.

The density of all the fabricated specimens was determined by the liquid displacement technique as stated above. For the samples with open pores, their density was calculated by an equation from the literature. The hardness (HV with a load of 98 N) of the hot-pressed billets was determined. Compressive tests at room temperature were carried out for both the hot-pressed and pressureless sintered samples to determine the compressive strength, \(S_c\); compressive true stress at crushing, \(\sigma_c\); compressive proportional limit, \(S_p\); compressive yield strength (offset = 0.2%), \(S_{cy}\); compressive engineering strain at crushing, \(e\); compressive true strain at crushing, \(e\); work done to crush the sample, \(W\); and toughness, \(T\), by employing a Gleeble 1500 and its adjoining computer system. X-ray diffraction phase analysis was carried out on the sintered samples. The interface between the ceramic and the metallic phase was examined by TEM.

For the purposes of comparison, the same experiments as stated above were conducted with the mixed material composed of \(\text{Al}_2\text{O}_3\) powder (without coating) and pure Ni powder. The starting \(\text{Al}_2\text{O}_3\) powder and pure Ni powder, as well as the volume ratio between the ceramic and the metal, were exactly identical with that of the mixture mentioned in the previous paragraphs.

### 3 RESULTS

#### 3.1 Densification

As mentioned in Section 2, the density of the starting \(\text{Al}_2\text{O}_3\) powder was determined to be \(3.957 \pm 0.001 \times 10^3\) kg/m\(^3\). This value is slightly lower than the value of the density of \(\text{Al}_2\text{O}_3\) given in literature, which is \(3.965 \times 10^3\) kg/m\(^3\) and \(3.985 \times 10^3\) kg/m\(^3\). This result indicates that some pores exist in the starting \(\text{Al}_2\text{O}_3\) particles. Figure 7 shows a scanning electron micrograph of a hot-pressed sample composed of 48.9 vol. \% \(\text{Al}_2\text{O}_3\) + 51.1 vol. \% Ni. Pores exist indeed in the dark areas which represent the \(\text{Al}_2\text{O}_3\) phase. This kind of pore could not be eliminated in this study. Therefore, in density calculations of this paper, the determined value of \((3.957 \pm 0.001) \times 10^3\) kg/m\(^3\) was taken as the full density of the \(\text{Al}_2\text{O}_3\) powder.

For a cermet composed of one ceramic constituent and one metallic constituent, if no chemical reaction or phase transformation takes place in the constituents, the theoretical density of the cermet can be calculated by the following equation:

\[
d_{\text{theor}} = \frac{1}{1 - x \frac{d_c}{d_m}}
\]

where

- \(d_{\text{theor}} = \text{theoretical density of the cermet} \left[10^3 \text{ kg/m}^3\right]\);
- \(d_c = \text{full density of the ceramic constituent} \left[10^3 \text{ kg/m}^3\right]\);
- \(d_m = \text{full density of the metallic constituent} \left[10^3 \text{ kg/m}^3\right]\);
- \(x = \text{weight fraction of the metallic constituent}\).

Choi et al. reported that the Ni and \(\text{Al}_2\text{O}_3\) system did not show the formation of new compounds at the interface at temperatures below

---

**Fig. 7.** Scanning electron micrograph of the cermet composed of 48.9 vol. \% \(\text{Al}_2\text{O}_3 + 51.1\) vol. \% Ni. It shows the pores inside the \(\text{Al}_2\text{O}_3\) particles.
1250°C.\textsuperscript{15} Also in this study, no evidence of chemical reactions or phase transformations in the temperature range tested (1150–1350°C) was found in the Al\textsubscript{2}O\textsubscript{3}+Ni system by X-ray diffraction phase analysis. Moreover, the Al\textsubscript{2}O\textsubscript{3}/Ni interface was examined by TEM. The electron diffraction patterns did not show any evidence of a new phase. Hence, the theoretical density of the cermet composed of 48.9 vol.\% Al\textsubscript{2}O\textsubscript{3} + 51.1 vol.\% Ni can be calculated by eqn (1) as 6.483 × 10\textsuperscript{3} kg/m\textsuperscript{3}.

For the cermet composed of 48.9 vol.\% Al\textsubscript{2}O\textsubscript{3}−TiN + 51.1 vol.\% Ni, either, no evidence of chemical reactions or phase transformations in the temperature range 1150–1350°C was obtained by X-ray diffraction phase analysis. Although we cannot exclude an interaction at the Al\textsubscript{2}O\textsubscript{3}/TiN and the TiN/Ni interface, the amount of the reaction layers (if any) would be tiny, as the content of the TiN coating is relatively low (see Section 2).\textsuperscript{16} Hence, these reaction layers would not influence the theoretical density of the cermet pronouncedly. Based on this assumption, eqn (1) was again used to calculate the theoretical density of the cermet to be 6.513 × 10\textsuperscript{3} kg/m\textsuperscript{3}.

Table 1 shows the effect of the TiN interlayer on the relative density of the cermets both hot-pressed and pressureless sintered at various temperatures. It can be seen that the relative density of the cermet with the TiN interlayer is

<table>
<thead>
<tr>
<th>Process</th>
<th>Hot pressing</th>
<th>Pressureless sintering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters of process</td>
<td>1150°C</td>
<td>1200°C</td>
</tr>
<tr>
<td></td>
<td>(41 MPa, 60 min)</td>
<td>(41 MPa, 60 min)</td>
</tr>
<tr>
<td>TiN interlayer</td>
<td>With</td>
<td>Without</td>
</tr>
<tr>
<td>Relative density (%)</td>
<td>92.6±0.3</td>
<td>91.2±0.4</td>
</tr>
<tr>
<td>Increment of relative density by TiN (%)</td>
<td>1.4±0.7</td>
<td>2.3±0.8</td>
</tr>
</tbody>
</table>

Fig. 8. The effect of the TiN interlayer on the engineering stress–strain diagram of the cermet hot-pressed at 1150°C and 41 MPa for 60 min (from compressive test).
Effect of titanium nitride interlayer on cermets

slightly higher than that without the interlayer. These results indicate that the TiN interlayer promotes the densification of the cermet during sintering. This favourable property can be attributed to the better wettability between TiN and Ni, as will be discussed in Section 4.

3.2 Mechanical properties

Figure 8 shows the engineering stress–strain diagrams during compaction of the cermets hot-pressed at 1150°C and 41 MPa for 60 min both with and without a TiN interlayer. This figure

![Graph](image1)

**Fig. 9.** The effect of the TiN interlayer on the engineering stress–strain diagram of the cermet hot-pressed at 1200°C and 41 MPa for 60 min (from compressive test).

![Graph](image2)

**Fig. 10.** The effect of the TiN interlayer on the engineering stress–strain diagram of the cermet pressureless sintered at 1150°C for 60 min (from compressive test).
indicates that in order to obtain the same strain, the cermet with a TiN interlayer always needs a higher stress compared with that without this interlayer. The diagrams of the cermets hot-pressed at 1200°C and 41 MPa for 60 min are shown in Fig. 9. Figures 10 and 11 present the diagrams of the cermets manufactured by cold-die compacting and pressureless sintering at 1150 and 1350°C, respectively. All the mechanical properties mentioned in Section 2 were determined or calculated. Also, the average and the uncertainty range (standard deviation) were calcu-

![Diagram](image)

**Table 2.** The effect of the TiN interlayer and the manufacturing conditions on the mechanical properties of the cermets

<table>
<thead>
<tr>
<th>Process</th>
<th>Hot pressing</th>
<th>Pressureless sintering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters of process</td>
<td>1150°C (41 MPa, 60 min)</td>
<td>1200°C (41 MPa, 60 min)</td>
</tr>
<tr>
<td>TiN interlayer</td>
<td>With</td>
<td>Without</td>
</tr>
<tr>
<td>( S_c ) (MPa)</td>
<td>716 ± 13</td>
<td>566 ± 12</td>
</tr>
<tr>
<td>Increment of ( S_c ) by TiN (%)</td>
<td>27 ± 5</td>
<td>47 ± 7</td>
</tr>
<tr>
<td>( \sigma_c ) (MPa)</td>
<td>603 ± 10</td>
<td>485 ± 11</td>
</tr>
<tr>
<td>Increment of ( \sigma_c ) by TiN (%)</td>
<td>24 ± 5</td>
<td>43 ± 7</td>
</tr>
<tr>
<td>( S_p ) (MPa)</td>
<td>401 ± 22</td>
<td>306 ± 23</td>
</tr>
<tr>
<td>Increment of ( S_p ) by TiN (%)</td>
<td>31 ± 17</td>
<td>51 ± 21</td>
</tr>
<tr>
<td>( S_{oa} ) (MPa)</td>
<td>464 ± 17</td>
<td>349 ± 24</td>
</tr>
<tr>
<td>Increment of ( S_{oa} ) by TiN (%)</td>
<td>33 ± 14</td>
<td>44 ± 14</td>
</tr>
<tr>
<td>Hardness (HV)</td>
<td>457 ± 20</td>
<td>326 ± 15</td>
</tr>
</tbody>
</table>

\( S_c \) = compressive strength.
\( \sigma_c \) = compressive true stress at cracking.
\( S_p \) = compressive proportional limit.
\( S_{oa} \) = compressive yield strength (offset = 0.2%).
<table>
<thead>
<tr>
<th>Process</th>
<th>Parameters of process</th>
<th>TiN interlayer</th>
<th>1150°C (41 MPa, 60 min)</th>
<th>1200°C (41 MPa, 60 min)</th>
<th>Pressureless sintering</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hot-pressing</td>
<td>Pressureless sintering</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1150°C (60 min)</td>
<td>1250°C (60 min)</td>
<td>1350°C (60 min)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>With</td>
<td>With</td>
<td>With</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Without</td>
<td>Without</td>
<td>Without</td>
</tr>
<tr>
<td>$\varepsilon$ (m/m)</td>
<td>0.227 ± 0.006</td>
<td>0.205 ± 0.010</td>
<td>0.212 ± 0.005</td>
<td>0.192 ± 0.009</td>
<td>0.319 ± 0.010</td>
</tr>
<tr>
<td>Increment of $\varepsilon$ by TiN (%)</td>
<td>11 ± 8</td>
<td>10 ± 7</td>
<td>7.0 ± 5.5</td>
<td>2.6 ± 2.0</td>
<td>2.6 ± 2.3</td>
</tr>
<tr>
<td>$\varepsilon$ (m/m)</td>
<td>0.257 ± 0.008</td>
<td>0.229 ± 0.012</td>
<td>0.238 ± 0.007</td>
<td>0.214 ± 0.011</td>
<td>0.384 ± 0.017</td>
</tr>
<tr>
<td>Increment of $\varepsilon$ by TiN (%)</td>
<td>12 ± 9</td>
<td>11 ± 9</td>
<td>8.5 ± 7.5</td>
<td>5.8 ± 2.8</td>
<td>2.9 ± 2.7</td>
</tr>
<tr>
<td>$W$ (J)</td>
<td>170 ± 7</td>
<td>131 ± 11</td>
<td>207 ± 10</td>
<td>137 ± 20</td>
<td>126 ± 7</td>
</tr>
<tr>
<td>Increment of $W$ by TiN (%)</td>
<td>30 ± 16</td>
<td>51 ± 29</td>
<td>19 ± 13</td>
<td>26 ± 11</td>
<td>136 ± 7</td>
</tr>
<tr>
<td>$\tau$ (MPa)</td>
<td>132 ± 4</td>
<td>96 ± 8</td>
<td>163 ± 9</td>
<td>105 ± 10</td>
<td>97 ± 6</td>
</tr>
<tr>
<td>Increment of $\tau$ by TiN (%)</td>
<td>38 ± 16</td>
<td>55 ± 23</td>
<td>16 ± 13</td>
<td>20 ± 10</td>
<td>112 ± 5</td>
</tr>
</tbody>
</table>

$\varepsilon$ = compressive engineering strain at crushing.
$\varepsilon$ = compressive true strain at crushing.
$W$ = work done to crush the sample.
$\tau$ = toughness (MPa) (as determined from the engineering stress–strain diagrams by calculating the area between the curve and the horizontal axis in the strain range from zero to $\varepsilon$).
lated based on the results of four tests conducted under identical conditions. Moreover, the relative increments of the mechanical properties of the cermets on applying a TiN interlayer were calculated. All of these results are listed in Tables 2 and 3.

From Figs 8–11 and Tables 2–3, it is clear that all the aforementioned mechanical properties of the cermets are improved by applying a TiN interlayer between the Al₂O₃ phase and the Ni phase. Sₐ, σₑ, Sₑ, Sᵥₑ, Hv, W and τ increase by 24–55% for hot-pressed samples and 10–34% for pressureless sintered samples. Obviously, the increments of the properties for the hot-pressed samples are always greater than those for the pressureless sintered samples manufactured at the same sintering temperature. Furthermore, the increments of the mechanical properties, except for ε and εₑ, increase with increasing sintering temperatures. Also, one can notice that for the samples with a TiN interlayer, the absolute values of the mechanical properties, except for ε and εₑ, increase with increasing sintering temperature within the temperature range tested.

From these experimental results, it can be concluded that a TiN interlayer remarkably improves the mechanical properties of the cermet based on Al₂O₃ and Ni. Since the Al₂O₃–TiN + Ni system includes two interfaces: the TiN/Ni one and the Al₂O₃/TiN one, the mechanical properties of this cermet cannot be good unless the adhesion at both the interfaces is strong. Therefore, the favourable effect of a TiN interlayer indicates that the adhesion at both the TiN/Ni interface and the Al₂O₃/TiN interface is stronger than that at the Al₂O₃/Ni interface involved in the Al₂O₃ + Ni system. Moreover, the increase in interface adhesion due to the TiN interlayer increases with increasing sintering temperature. Furthermore, the adhesion at the TiN/Ni interface or at the Al₂O₃/TiN interface (or both) improves with higher sintering temperature. All of these results will be explained or discussed in the next section as well as in subsequent papers. ¹¹,¹⁶

In addition, it should be mentioned that the experimental results concerning the mechanical properties of the cermets are consistent with the observed densifications as shown in Table 1, although it is remarkable that a slight increment in relative density is accompanied by such a pronounced increment in mechanical properties. A better understanding for this follows from the microstructural investigation, as will be shown in a subsequent paper. ¹¹

4 DISCUSSION

4.1 Porosity dependence of strength

The relationship most widely used to describe the porosity dependence of strength for ceramic materials is the exponential relation ¹⁷

\[ S = S₀ \exp (-bp) \] (2)

where

- \( p \) = porosity of the material;
- \( S \) = strength at porosity \( p \) (MPa);
- \( S₀ \) = strength at zero porosity (MPa);
- \( b \) = dimensionless empirical constant.

Equation (2) is an empirical formula, which was suggested for the first time by Duckworth based on the principle of the remaining load-bearing cross-section of the matrix and the minimum distance between pores. ¹⁷,¹⁸ In this equation, the empirical constant \( b \) represents the degree of porosity dependence of strength of the materials. Several researchers reported that the experimental data of polycrystalline alumina obey the exponential relation of equation (2) very well. ¹⁷,¹⁹–²³

From eqn (2), we obtain

\[ \ln S = -bp + \ln S₀ \] (3)

Equation (3) shows a linear relationship between \( \ln S \) and \( p \). The experimental data of the cermets obtained in this study have shown the presence of this linearity, which indicates that eqn (2) is applicable for the cermets as well. The values of \( b \) and \( \ln S₀ \) have been obtained by linear regression analysis based on the experimental results from hot-pressing for each kind of material. For the cermet composed of 48.9 vol. % Al₂O₃–TiN + 51.1 vol. % Ni, we found:

\[ b = 8.5 \]
\[ S₀ = 1400 \text{ MPa (compressive strength)} \]

and for the cermet composed of 48.9 vol. % Al₂O₃ + 51.1 vol. % Ni:

\[ b = 5.7 \]
\[ S₀ = 940 \text{ MPa (compressive strength)} \]
These results indicate that the compressive strength at zero porosity of the cermet with a TiN interlayer is about 50% higher than that without the interlayer.

4.2 Wettability

The contact angle between $\text{Al}_2\text{O}_3$ and Ni in vacuum at 1500°C is 128°, whereas the contact angle between TiN and Ni in vacuum at 1550°C is about 70°. The better wettability between TiN and Ni compared to $\text{Al}_2\text{O}_3$ and Ni implies a better affinity and stronger adhesion between TiN and Ni at high-temperature solid-state sintering and this will contribute to the sintering process and improve mechanical properties of the product. In addition, the results also show a strong adhesion between the $\text{Al}_2\text{O}_3$ and the TiN coating layer. Therefore, for the cermet with the TiN interlayer, the relative density is higher and the mechanical properties are better than for the cermet without the interlayer.

The effect of a TiN interlayer on the microstructure of the cermets will be discussed in a subsequent paper, in which the experimental results presented in this paper will be explained from a microstructural point of view.

5 CONCLUSIONS

The study of the densification and properties of the $\text{Al}_2\text{O}_3$-TiN + Ni and the $\text{Al}_2\text{O}_3$ + Ni systems within the applied processing conditions indicates the following:

— The TiN interlayer promotes the densification of the cermet during either hot-pressing or pressureless sintering. The higher the temperature employed, the more pronounced the effect is.

— A TiN interlayer remarkably promotes the mechanical properties of the cermets based on $\text{Al}_2\text{O}_3$ and Ni. The higher the temperature, the more pronounced the beneficial effect is. The favourable effect of the TiN interlayer on the mechanical properties of the cermets produced by hot-pressing is greater than that for the cermet made by pressureless sintering. These results indicate that the adhesion at both the TiN/Ni interface and the $\text{Al}_2\text{O}_3$/TiN interface involved in the $\text{Al}_2\text{O}_3$-TiN + Ni system is stronger than that at the $\text{Al}_2\text{O}_3$/Ni interface involved in the $\text{Al}_2\text{O}_3$ + Ni system. Moreover, the difference of interface adhesion between these two systems increases with increasing sintering temperature.

— The reason for the improvement in densification and properties is the better wettability of TiN/Ni compared to $\text{Al}_2\text{O}_3$/Ni.

— For the $\text{Al}_2\text{O}_3$-TiN + Ni system, the mechanical properties, except $e$ and $\epsilon$, increase with increasing sintering temperature, revealing a temperature dependence of interface adhesion.

ACKNOWLEDGEMENT

The authors would like to express their thanks to Mr C. A. Booze, Mr A. van Wageningen, Mr M. A. Smithers and Mr R. Nijkamp for their help and assistance with the materials and the experimental work.

REFERENCES


16. Li, S., Maas, J. H., Boeijsma, J. & Kolster, B. H., Diffusion at interfaces in cermets based on alumina and nickel with a titanium nitride interlayer. (in preparation).


