Original Article

Microstructure, wear, and corrosion characterization of high TiC content Inconel 625 matrix composites

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ABSTRACT

Titanium carbide/Inconel 625 (nickel alloy) metal matrix composites (MMCs) are developed for the combination of the super mechanical and corrosion properties of nickel alloy matrix and the high hardness of reinforcing titanium carbide particles (TiC\textsubscript{p}). The microstructure, hardness, wear, and corrosion behavior of MMCs with different volume contents of TiC\textsubscript{p} (25, 50 and 70 vol.\%) were investigated. The effect of increasing TiC\textsubscript{p} on the intermetallics and precipitates formed was examined using SEM/EDS and XRD analyses. The tribological behavior of the MMCs was investigated using wear testing with a pin-on-disk machine. The corrosion behavior was examined using potentiodynamic polarization experiments in 3\% (w/v) NaCl solution. The results showed that the addition of TiC\textsubscript{p} into the Inconel 625 alloy resulted in formation of several intermetallics such as MoNi\textsubscript{p}, Cr\textsubscript{2}Ni\textsubscript{3} and MoCr, in addition to molybdenum and chromium carbides in the matrix alloy. A great improvement in the hardness was resulted with addition of 25 vol.\% TiC\textsubscript{p} and consequently the wear resistance was also improved. Further increase of TiC\textsubscript{p} from 50 to 70 vol.\% did not result in more improvement of both hardness and wear resistance. The corrosion resistance of TiC\textsubscript{p} (25 vol.\%) composite was comparable to that of monolithic Inconel 625 matrix alloy, while clear reduction in the corrosion resistance was found in the 50 and 70 vol.\% composites.

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1. Introduction

Ni-based superalloy Inconel 625 has a good combination of yield/creep/fatigue strength and excellent oxidation/corrosion resistance. Inconel 625 has higher tensile properties when compared with other Ni-base alloys such as Inconel 718 [1]. It has been widely used in aerospace, chemical, petrochemical and nuclear industries for decades [2]. Further improvement of hardness and wear resistance can be achieved through reinforcing of the Inconel 625 alloy with harder ceramic particulates such as TiC [3] and CrC [4].

TiC is considered as one of the most suitable reinforcing material by having distinguished properties such as high melting point (3067 °C), moderate density (4.93 g/cm³), extreme hardness (2800–3200 HV), high mechanical strength, and good thermal and electrical conductivities [5,6]. Nickel, as well as its alloys, is a superior matrix for TiC-reinforced composites, because it has high toughness and ductility, high corrosion resistance, and exceptional oxidation resistance at high temperatures [7]. In addition to the type of composite constituents, microstructure and fabrication method play an important role in determining the wear resistance of TiC/Ni MMCs [8]. TiC/Ni MMCs have outstanding mechanical and physical performance even at high temperatures for refractory, abrasive, and structural applications, where upgraded resistance to wear and corrosion is aimed [9,10].

TiC reinforcing particles serve as wear resistance agent for Ni-based alloy if used either as a bulk composite or as a surface coating Ni-based composite for a substrate of steel [11,12] or aluminum [13]. Composites of Ni-based alloys with reinforcement of TiCp up to 50% are used for the coating of carbon steel [11,14]. It was found that the coatings of Ni-based composite with 30 vol.% TiC on carbon steel exhibit excellent wear resistance [11]. Their friction coefficients and wear rates are dramatically decreased compared with coatings of pure Ni-based alloy [11]. Wear resistance of Ni-Mo alloy reinforced with TiC content of 50 vol.% was found to be increased [12]. It was also reported that Ni-alloy having Mo showed increased bonding between TiC and the matrix [12,15,16] where Mo-rich shell incorporated the entire TiC and performed as a binding enhancing agent. This has increased wear resistance of the Ni-based alloy reinforced with TiC [15]. TiC/stainless steel 303 composite coating produced by TIG surface remelting has clearly enhanced the wear resistance of stainless steel 303 substrate [17]. TiC-reinforced Ni based alloy composite coating produced by plasma spraying has improved the wear resistance of aluminum alloy AA7005 [13].

Corrosion resistance of Inconel 625 superalloy is outstanding in aggressive environments. However, incorporation with TiCp may deteriorate the corrosion resistance of Inconel 625 MMC. In general, inferiority in the corrosion resistance of MMCs, which ranges between slight to significant amount, can be attributed to one or more of the following reasons [18]: (1) galvanic coupling of the reinforcement constituent and matrix alloy [19,20], (2) formation of an interfacial phase between the reinforcement and matrix [21], and (3) microstructural changes and processing contaminants resulted from manufacture of the MMC [22]. The electrical conductivity of the reinforcing ceramic can contribute to the galvanic corrosion of the matrix alloy.

Thus, the aim of this work was to study the effect of increasing the volume percentage of TiCp on the wear and corrosion behavior of TiCp/Inconel 625 matrix composites with the deep focus on the underlying effects of the TiCp on the type and size of the intermetallic precipitates formed in the Inconel 625 matrix. For this purpose the Inconel 625, a Ni-based alloy, and its composites with TiCp were investigated in the as prepared and after different testing using scanning electron microscopy (SEM) equipped with EBSD/EDS analysis system and also using X-ray diffraction (XRD) analysis.

2. Materials and methods

2.1. Materials

A Ni-based superalloy, the Inconel 625 alloy, of typical composition listed in Table 1 was used as the metallic matrix and TiCp as the reinforcement. The TiCp/Inconel 625 MMCs were supplied by Institute for Materials Testing and Technology, Clausthal, Germany, as cylindrical bars of 10 mm diameters. The composites were produced by the squeeze casting technique with infiltration of the matrix (Inconel 625) melt at 1650 °C into a preform of the reinforcing TiCp. The composites were in three different volume percentages of 25, 50 and 70 TiCp.

2.2. Microstructure investigation and hardness testing

Metallographic investigation was carried out on the sample cross sections of the TiCp/Inconel 625 MMCs as well as the monolithic alloy. The samples were prepared according to the standard metallographic technique using mechanical grinding and polishing. Composite samples were investigated in the as polished conditions, where the TiC particles were distinguishable. The grain structure of the monolithic alloy was investigated using the electron back scattering diffraction (EBSD) technique on the Quanta FEG 250 scanning electron microscopy (SEM) equipped with EDS and EBSD systems. The SEM was also used to investigate the composite microstructure and the worn surface after wear testing of the monolithic and composite materials. EDS analysis for elemental and phase maps was carried out using a scan step size of 0.3 μm. XRD analysis was carried out using a Siemens D5000 equipped with Cu Kα radiation with a nickel filter at 40 kV and 30 mA. The specimens were tested within the range of 10° < 2θ < 100°. Diffraction signals were processed by DIFFRAC-plus software.

| Table 1 – Typical chemical composition of the Inconel 625. |
|-----------------|---|---|---|---|---|---|---|---|---|---|---|---|
| Element        | Ni | Cr | Mo | Fe | Nb | Ti | Mn | Al | Si | Co | C |
| wt.%           | 60.35 | 21.73 | 9.11 | 3.94 | 3.89 | 0.27 | 0.21 | 0.19 | 0.16 | 0.09 | 0.06 |
Hardness measurements of the samples were carried out using Rockwell hardness tester with a test load of 60 kg (HRA). The hardness values were calculated as average of eight test results for each sample.

2.3. Wear testing

The wear testing of the TiCp/Inconel 625 MMCs and the monolithic alloy was performed on a pin-on-disk wear tester under dry condition. The wear test samples were machined into cylindrical specimens (diameter = 8 mm, height = 20 mm) from the produced composite cylindrical bars. The wear test specimen surface was ground using SiC paper till grade 800 before testing. The sliding counter face disk was made of grinding stone of fine aluminum oxide having a hardness of 100 HRA. The test was performed at room temperature without lubricant. The counter disk and the specimen face were cleaned by acetone just prior to wear testing. Wear test was first carried out for a constant time of 15 min using different loads ranging between 0.5 and 1.5 kgf on the TiCp (50%)/Inconel 625 MMC specimen in order to determine which load is suitable for applying the further wear tests. The 1.5 kgf load was selected as a constant load for further wear tests using variable running times from 5 to 25 min. Considering the arm of the acting load, the applied load on the wear test specimen is 5.08 N which is equivalent to an applied stress of 64.7 kPa. The selected running distance for the next wear tests was 7.4 km. Wear test results were averaged for three wear tests for each material.

2.4. Corrosion testing

Potentiodynamic polarization experiments were carried out in 3% (w/v) NaCl solution at room temperature using a potentiostat (model M Lab) controlled by a PC. Before corrosion testing, a fresh surface on one cross-section face of specimen was obtained by wet grinding using SiC papers down to 1200 grit. Then, the specimen was rinsed several times in ethanol. Finally, the specimen was wrapped with a copper wire and coated with insulating lacquer from all sides leaving the one cross-section freshly prepared. Polarization tests were carried out in conventional three-electrode cell containing 1l of NaCl solution, in which the specimen was suspended as a working electrode and the counter electrode was a Pt rod. Prior to potentiodynamic polarization, the specimen was exposed to the NaCl solution for 30 min, by which time a stable potential – open circuit potential (OCP) – was monitored. With reference to saturated calomel electrode (SCE), the polarization was obtained by scanning from 500 mV more negative than the OCP at a rate of 10 mV/min. Scanning continued in the noble direction until a sharp rise in the current, indicating the onset of pitting, was obtained. The corrosion current density (Icorr), corrosion potential (Ecorr), and break-through potential, namely pitting potential (Ep), were determined using the software program “MlabSci444”. The Icorr was determined by extrapolation of Tafel lines of each polarization curve. The Ep was determined as the potential at which the current density exceeded 10 µA/cm² for curves showing passive behavior. For pseudo-passive curves, however, Ep was considered as the break-through potential at which the current increased sharply.

3. Results and discussion

3.1. Microstructure

Fig. 1 shows the microstructure of the Inconel 625 alloy and TiCp/Inconel 625 MMCs containing three different volume fractions of TiCp. Fig. 1a shows the inverse pole figure (IPF) coloring orientation image map of the monolithic matrix alloy (Inconel 625) with the high angle grain boundaries >15° superimposed in black lines. It can be observed that the monolithic alloy consists of recrystallized grain structure with high density of twin boundaries which is a typical feature of this alloy. The back scattered SEM micrographs of the composite materials of different TiCp volume fractions (25, 50 and 70%) are illustrated in Fig. 1b, c, and d respectively. The microstructure consists mainly of dark gray areas and light gray areas with white spots spread inside. The dark gray areas represent the TiCp, and the light gray areas represent the matrix alloy. TiC particles have irregular shape with very sharp edges. It can also be observed that there are some black areas in the composites with higher TiCp volume fractions (50% and 70%) indicated by arrows in Fig. 1c and d. These black areas represent lack of penetration zones.

Fig. 1e presents the frequency distribution of the grain size of the monolithic matrix shown in Fig. 1a. The grain size distribution ranged from 4.8 to 107 µm, with a clear distribution discontinuity between 65 and 107 µm. The mean size was estimated to be 30.4 µm. Fig. 1f shows the typical particle distribution of TiCp measured from Fig. 1d (70 vol.% TiCp/Inconel 625). The TiC particle size ranged from 1 to 19 µm. The distribution of TiC particle size was continuous up to 15.3 µm, and its mean size was about 7 µm.

In the composite containing low volume percentage of TiCp (25%), the particles were well surrounded by the matrix (Fig. 1b). While, in the composites containing higher percentages of TiCp (50% and 70%), the matrix alloy did not perfectly penetrate through the TiCp due to the high percentage of TiCp. Example of this lack of penetration zones are the black areas indicated by arrows as shown in Fig. 1c and d. This lack of matrix penetration is a typical defect in composites with higher percentages of reinforcing component [23–25]. However, the regions indicated as lack of matrix penetration could be much smaller than shown, and it was enlarged by decohesion of some TiC particles during mechanical metallographic preparation. Moreover, careful observation on the round “grain-like” matrix areas in the TiCp/Inconel composites showed numerous small islands of precipitates which are brighter than the surrounding matrix (Fig. 1b, c, d). These precipitates were closely investigated as shown below.

Fig. 2 shows the EDS elemental map for the TiCp (50%)/Inconel 625 MMC. The values shown in the side legend of Fig. 2 indicate the elemental area percent based on pixel count of the colors representing the elements. The separate elemental analysis is shown in Fig. 3a–f for the elements C, Mo, Ti, Cr, Fe, and Ni. Fig. 3 shows that the small precipitates
in the alloy matrix were composed of Cr-rich and Mo-rich phases. The Mo-rich precipitates were fine dispersed inside the matrix grain-like zones. However, the Cr-rich precipitates were located at the matrix areas close to the TiCp.

The phase analysis (Fig. 3 and Table 2) of the Mo-rich precipitates and the Cr-rich precipitates led to the speculation that they are mainly composed of Mo–Ni phase and Cr–Mo phase, respectively. The highest elemental percentages in the former
phase were for Mo and Ni, whereas the latter phase was rich in Cr and Mo. Appearance of other elements in each phase can be ascribed to interaction of EDS electron beam with surrounding matrix alloy. Further XRD investigations (given below) revealed the chemical composition of Cr-rich and Mo-rich precipitates to be MoCr and MoNi phases, respectively.

The elemental composition of those phases listed in Table 2 shows the presence of high atomic percentages of carbon in both precipitates. This indicates the presence of molybdenum and chromium carbides in the detected precipitates in the matrix regions. Although the Inconel 625 is very low in carbon content, M₆C and M₂₃C₆ carbides are possibly formed during thermal exposure, where M is principally Cr, Mo, and Ni [26]. In TiCₚ/Inconel 625 MMCs, carbon can be dissociated from TiC during the liquid infiltration production process and forms Cr carbides. According to standard free energy of formation for carbides [27], Cr₇C₃ is thermodynamically more stable than TiC at temperature above 1200 °C, which is reached during the production by infiltration casting processes associated with preheating of the TiCₚ preform. Similar Cr-carbides were noticed in stainless steels AISI 440 reinforced with 25 vol.% of niobium carbide (NbC) particles [28].

Further identification of the different intermetallic compounds formed in the TiCₚ/Inconel MMCs was carried out using XRD analysis. The XRD results of the Inconel alloy and its composites are shown in Fig. 4. It can be implied from the XRD results that: (1) the TiC intensity increases with increasing the TiC content, (2) the intensities of MoNi₄, Cr₂Ni₃, and MoCr peaks decrease with increasing the TiCₚ content and (3) in agreement with the EDS analysis (shown in Fig. 3b, c) chromium and molybdenum carbide precipitates were too little to be detected by XRD. The decrease in the intensity of the MoNi₄Cr₂Ni₃ and MoCr intermetallics in the TiCₚ/Inconel MMCs with increasing the TiC content is mostly related to the possible depletion of Cr and Mo due to the formation of carbides with increased chance of finding carbon atoms from the TiCₚ.

### 3.2. Hardness

Hardness results in Rockwell scale (HRA) of Inconel 625 alloy and TiCₚ/Inconel 625 MMCs are presented in Fig. 5. It can be seen that the reinforcing with TiCₚ significantly increased the hardness values relative to the hardness of the matrix alloy. Addition of 25 and 50 vol.% of TiCₚ to Inconel led to increase of

Table 2 – Elemental analysis of the Mo- and Cr-rich precipitates in TiCₚ (50%)/Inconel 625 MMC shown in Fig. 3.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Mo-rich phase (Mo–Ni–Cr–Ti)</th>
<th>Cr-rich phase (Cr–Mo–Ni–Ti)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight%</td>
<td>Atomic%</td>
</tr>
<tr>
<td>C</td>
<td>9.50</td>
<td>36.64</td>
</tr>
<tr>
<td>Mo</td>
<td>33.68</td>
<td>16.27</td>
</tr>
<tr>
<td>Ti</td>
<td>3.34</td>
<td>3.23</td>
</tr>
<tr>
<td>Cr</td>
<td>15.71</td>
<td>14.00</td>
</tr>
<tr>
<td>Fe</td>
<td>1.51</td>
<td>1.26</td>
</tr>
<tr>
<td>Ni</td>
<td>36.26</td>
<td>28.61</td>
</tr>
</tbody>
</table>
the hardness by 36 and 45%, respectively. Further increasing of TiC<sub>p</sub> to 70 vol.% did not lead to a proportional increase of the hardness value, but it has resulted in a little decrease of the hardness value compared with the TiC<sub>p</sub> (50%)/Inconel MMC. This could be related to the lack of penetration of the matrix alloy into the TiC<sub>p</sub> agglomerates (as shown in Fig. 1c, d), which makes debonding of the TiC<sub>p</sub> from the materials is possible.

3.3. Wear

The wear test results are displayed in Fig. 6 in terms of the weight loss. The unreinforced Inconel alloy showed very high weight loss compared with the composite materials. However, the TiC<sub>p</sub> (25%)/Inconel MMC displayed very low weight loss that represents only 4.8% of the weight loss of the unreinforced Inconel. The composites with higher TiC<sub>p</sub> contents of 50 and 70 vol.% showed nearly equal weight loss, which was only ~2.9% of the weight loss of the Inconel alloy. Representing the wear rate against the volume fraction of TiC<sub>p</sub>, Fig. 7 showed that incorporation of 25 vol.% of TiC<sub>p</sub> decreased significantly the wear rate of the Inconel 625 alloy. Increasing more than 50 vol.% of TiC<sub>p</sub> has no significant effect on further decreasing of the wear rate lower than that achieved for the TiC<sub>p</sub> (50%)/Inconel composite.

Fig. 8 shows the worn surfaces of the Inconel and its composites. The unreinforced Inconel depicted deep scratches and clear plastic deformation leading to removal of wear debris, Fig. 8a. Fig. 8b depicts higher magnification of Fig. 8a showing the plastic deformation accompanying the deep scratches which lead to separation of the metallic debris from the matrix alloy. Such severe abrasive wear resulted in the high wear loss shown in Fig. 6. The wear effect in the Inconel in the form of deep scratches had almost disappeared in worn surface of the TiC<sub>p</sub>/Inconel composites shown in Fig. 8c, d. The amount of TiC<sub>p</sub> shown in Fig. 1 could not be seen in the images of the worn surface due to the smearing effect of Inconel matrix. The worn surface of the TiC<sub>p</sub> (25%)/Inconel MMC revealed fine cracks in the matrix region, Fig. 8c.

Formation of such cracks has been also found on the worn surface of the TiC/Ni-based coating under wear load of 12 N [13]. It was ascribed to the hardening of the matrix due to the repeated running on hard ceramic counter disk [13]. The current study showed that the wear rate of TiC<sub>p</sub> (25%)/Inconel composite was only ~3.3% of the monolithic matrix alloy. Cai et al. [11] have found that the wear rate and the friction coefficient of TiC<sub>p</sub> (30%)/Ni-based composite is about one third that of the pure Ni-based alloy coating [11].

3.4. Corrosion behavior

The corrosion performance of monolithic nickel alloy (Inconel 625) and its composites with various fractions of TiC<sub>p</sub> was
tested in 3% (w/v) NaCl solution. Fig. 9 shows the potentiodynamic polarization curves of the alloy and composites as semi-logarithmic current density versus potential plots. The results showed that the polarization curves of MMC specimens were slightly shifted in the noble direction, and much higher current densities were observed compared to those of the monolithic Inconel alloy specimen. Corrosion parameters listed in Table 3 presents a clearer comparison between the pure nickel alloy and its composites.

It is seen that the presence TiC_p in the Ni MMCs shifted the corrosion potential (E_corr) in the noble direction, and as the TiC_p contents increased the E_corr became nobler. This implies the existence of galvanic coupling between Ni alloy and TiC_p, by virtue of the high electrical conductivity of TiC [29]. The comparison of the corrosion current density "I_corr" values showed that the presence of 25 vol.% TiC_p slightly increased the I_corr of Ni alloy. Further increase in vol.% of TiC_p raised the I_corr to be around one order of magnitude higher than that of the monolithic Inconel alloy.

In a like manner, the 25% TiC_p and 50% TiC_p MMC specimens showed a passive or a pseudo-passive behavior with monitoring passive current density values around one order of magnitude higher than the virtual passive current density recorded by the monolithic Inconel 625 alloy, see Table 3. The 70 vol.% TiC_p MMC specimen lost its passivity showing

**Fig. 8** - Worn surfaces after running distance of 7.4 km under a wear load of 5.08 N. (a) Inconel 625 alloy; (b) higher magnification of (a); (c) TiC_p (25%)/Inconel; and (d) TiC_p (50%)/Inconel.

**Fig. 9** - Potentiodynamic polarization curves of the Inconel 625 alloy and its composites in 3% (w/v) NaCl aqueous solution.

### Table 3 - Corrosion data of the investigated Inconel 625 alloy and its composites.

<table>
<thead>
<tr>
<th>TiC vol.%</th>
<th>E_corr, mV</th>
<th>I_corr, µA/cm²</th>
<th>I_pass, µA/cm²</th>
<th>E_r, mV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>−197</td>
<td>0.234</td>
<td>0.503</td>
<td>457</td>
</tr>
<tr>
<td>25</td>
<td>−173</td>
<td>0.392</td>
<td>3.41</td>
<td>412</td>
</tr>
<tr>
<td>50</td>
<td>−143</td>
<td>2.149</td>
<td>14.76</td>
<td>288</td>
</tr>
<tr>
<td>70</td>
<td>−139</td>
<td>4.029</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
an active behavior. Another parameter of comparison is the pitting potential ($E_p$), where the presence of TiC$_p$ reduced the $E_p$ of the monolithic Ni alloy to less noble values.

Consequently, it can be reported that the presence of TiC$_p$ adversely affected the passivity of Inconel 625 alloy. This loss in passivity can be ascribed to discontinuity of the passive film formed on MMC specimens. The inferiority of corrosion resistance of TiC$_p$/Inconel 625 is unlikely to be attributed to corrosion of TiC itself. TiC is a high corrosion resistant material and shows passive behavior in many solutions, even acidic ones. Its passivity, however, breaks up in concentrated (1 M) HCl solution, by showing a high oxygen overpotential [30]. Referring to Pourbaix diagram for the TiC–H$_2$O system, it is seen that TiC is passive in a very wide range of pH values, it corrodes only at extremely low and at extremely high pH values. In addition, the TiC immunity region expands up to more active potentials [31]. In contrast to TiC, highly active behavior of C-fibers in C$_p$/Mg MMC when undergoes electrochemical polarization in chloride aqueous solutions leads to crevice corrosion at C$_p$/Mg interface. This results in a wide reduction of $E_p$ to about 1000 mV more negative than that of the Mg matrix alloy [32]. Also, aluminum carbide formed as interfacial compound in Gr/Al MMC reduces the $E_p$ of its matrix alloy to 600 mV in the negative direction [21]. However, in the present study the presence of TiC$_p$ slightly reduced the $E_p$ of the Inconel matrix, implying the slight effect of any interfacial phase probably formed.

Finally, the results of corrosion investigations revealed that TiC$_p$ incorporation decreased the corrosion resistance of Inconel 625 alloy, but the effect of TiC was slight particularly when added in small contents up to 25 vol.% TiC$_p$. Higher vol.% of TiC$_p$ led to deterioration of corrosion resistance due to the galvanic effect induced by TiC$_p$ and due to the massive discontinuity of the passive film. This results not only from discontinuity at TiC$_p$/Inconel interface but also from presence of pores of lack of matrix penetration, as shown in Fig. 1c and d. The findings of the present corrosion study were in general agreement with a previous study on the corrosion of TiC/Inconel 625 MMC [33]. Also, a recent study reported that 6% TiC addition to 304 stainless steel increases the corrosion rate of the composite to be about 1.5 of the matrix alloy [34]. Although the presence of TiC leads to propagation of numerous pits over 304 stainless steel surface, it decreases significantly the pits depth.

4. Conclusions

The following conclusions can be drawn from the given experimental study on the microstructure, wear behavior, and corrosion behavior of TiC$_p$/Inconel 625 MMCs with different high volume percent (25, 50, and 70 vol.%) of TiC$_p$:

- Formation of the intermetallics MoNi$_3$, Cr$_2$Ni$_3$ and MoCr, in addition to molybdenum and chromium carbides in the matrix of TiC$_p$/Inconel 625 MMCs.

- Increasing TiC$_p$ up to 50 and 70 vol.% resulted in lack of matrix penetration into intensive agglomerates of TiC$_p$.

- The wear resistance as well as the hardnes of Inconel 625 MMC were greatly improved by reinforcing with TiC$_p$ (25 vol.%). Further increase in TiC$_p$ to 50 and 70 vol.% did not result in clear decrease in the wear rate.

- The corrosion behavior of TiC$_p$ (25%)/Inconel 625 MMC was comparable to that of monolithic Inconel 625 matrix alloy. However, MMCs with higher volume fractions of TiC$_p$ (50 and 70%) showed higher corrosion rates with deterioration of passivity.

Conflicts of interest

The authors declare no conflicts of interest.

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