Ti-based Quasicrystal Layers Produced by Plasma Thermal Spraying

Akito Takasaki[1,a], Susumu Uematsu[2,b], and K.F. Kelton[3,c]

[1]Center for Energy Flow Research, Research Organization for Advanced Engineering and Department of Mechanical Engineering, Shibaura Institute of Technology, Toyosu, Koto-ku, Tokyo 135-8548, Japan
[2]Advanced Maritime Transport Technology Department, National Maritime Research Institute, Mitaka, Tokyo 181-0004, Japan
[3]Department of Physics and Center for Materials Innovation, Washington University, St. Louis, Missouri 63130, USA
[a]takasaki@sic.shibaura-it.ac.jp, [b]uematsu@nmri.go.jp, [c]kfk@wuphys.wustl.edu

Abstract

$Ti_{45}Zr_{38}Ni_{17}$ powders were thermally sprayed onto mild steel substrates in air and under a reduced pressure of argon. Several oxides were formed after thermally-spraying the mechanically-alloyed powders in air. After spraying in a reduced pressure of argon, the coating layers obtained from the gently mixed powders consisted of the elemental metals, but an amorphous phase primarily appeared in the thermally-sprayed mechanically-alloyed powders, which transformed into the icosahedral quasicrystal phase and a minor Ti_2Ni-type crystal phase after annealing at 828 K. The Vickers hardness and the contact angle with pure water for the quasicrystal layers were about 7 GPa and 92° respectively.

Keywords : quasicrystal, thermal spraying, mechanical alloying, Ti-Zr-Ni

1. Introduction

Numerous kinds of quasicrystals, displaying non-crystallographic rotational symmetry, have beem found since the report of the first quasicrystal in an aluminumalloy by Shechtman et al [1].

The thermodynamically stable Ti-Zr-Ni icosahedral quasicrystals can absorb hydrogen to a level exceeding that of traditional metal hydrides, such as $LaNi_5$ and TiFe, indicating their potential as new hydrogen-storage materials [2]. To extend the possible engineering applications for the Ti-based quasicrystals, we have attempted to produce the quasicrystal coating layers by plasma thermal spraying, in which the Ti-Zr-Ni powders supplied to the spraying are either gently mixed powders or mechanically-alloyed ones. Some fundamental physical properties, such as hardness and contact angle of the produced layers with pure water, are also investigated.

2. Experimental and Results

Commercially pure Ti (99.9 %), Zr (99.9 %), and Ni (99.9 %) elemental powders were used as starting materials. The powder mixtures, whose chemical compositions were $Ti_{45}Zr_{38}Ni_{17}$, were blended by two kinds of methods. For one typethe powders were mixed gently (manually) in a vial, and for the other type they were mechanically alloyed by a planetary ball mill.

Thermal spraying was carried out with an Ar-He plasma either in air or under a reduced pressure of argongas. Thermal spraying under a reduced pressure of argonwas performed in a vacuum chamber, which was pumped down by a rotary pump and then back filled with argon gas to the vacuum level of about 33 kPa. The arc voltage and current were 34 V and 600 A respectively. The powders were sprayed onto mild steel substrates whose dimensions are30 X 30 mm^2 (thickness was 3 mm).

3. Results and Discussion

The MA powders used for thermal spraying were obtained after MA for 20 h. This MA process turned the elemental powders into an amorphous state, while the gently mixed powders were still a combination of three kinds of elemental metals.

The thermally-sprayed layers in air obtained from Themechanically-alloyed powders were consited of several kinds of oxides, such as ZrO_2, Ni_3Ti_5, $ZrTiO_4$, and a $Ni_{11}Zr_9$ intermetallic compound. To eliminate the oxide products from the coating layers, thermal spraying under a reduced pressure of argon was performed. Fig.1 (a) and (b) show XRD patterns for thermally-sprayed layers produced under a reduced pressure of argon, in which the supplied powders to the spraying are the gently-mixed and mechanically-alloyed ones respectively. The effect of the number of transverse scans for thermal spraying is also shown for the mechanically-alloyed powders (Fig.1 (b)). It is clearly shown that oxidation during thermal spraying could be

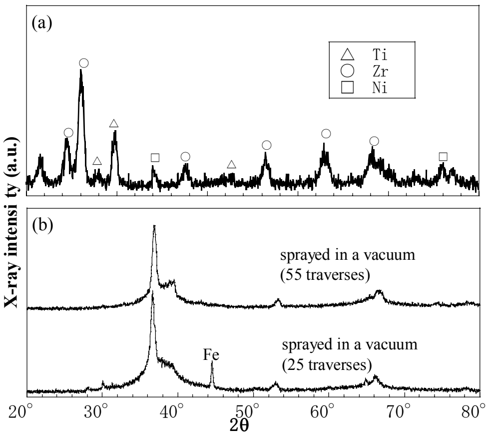

Fig. 1. X-ray diffraction patterns for thermally-sprayed $Ti_{45}Zr_{38}Ni_{17}$ layers under a reduced pressure of argon, obtaianed from (a) gently-mixed powders and (b) mechanically-alloyed powders.

prevented for each powder. For the gently-mixed powders, the elemental metals, such as Ti, Zr, and Ni, still remain even after thermal spraying. The XRD pattern for the mechanically-alloyed powders (amorphous), on the other hand, contains a very broad peak and comparatively sharp peaks, indicating that an amorphous and a minor crystal phase coexist after thermal spraying. A possible crystal structure for the minor phase is a body centered cubic (bcc) one with a lattice parameter of 0.342 nm, which is very close to the high-temperature phase of Ti/Zr (β -Ti/Zr).

The thermally-sprayed amorphous layers (also containing a minor phase) produced from the mechanically-alloyed powders were annealed in vacuum at a temperature of 828 K. The XRD pattern obtained after annealing is shown in Fig. 2. Two sharp and one weak XRD peaks were observed at about 2 θ=36˚, 39˚ and 64˚ respectively, which can be indexed to the icosahedral quasicrystal. The indices shown in Fig. 2 were obtained by the scheme suggested by Elser [3]. Besides these peaks corresponding to the quasicrystal phase, two very weak XRD peaks are also observed at 2θ= 32˚ and 66˚, which can be indexed to a Ti_2Ni-type crystal phase (face-centered cubic structure).

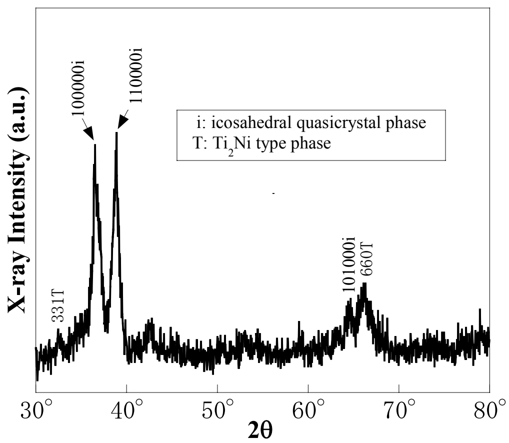

Fig. 2. X-ray diffraction pattern for thermally-sprayed $Ti_{45}Zr_{38}Ni_{17}$ layers obtained from mechanically-alloyed powders after annealing at 828 K.

The Vickers hardness of the thermally-sprayed layers obtained from the gently mixed powder was about 3.5 GPa. That of the layers just obtained from the mechanically-alloyed powder (amorphous) was about 6.5 GPa, and increased slightly to 7 GPa after annealing (to obtain the quasicrystal). The contact angles with pure water in air at room temperature were meaured to be about 70° for the sprayed layers obtained from the gently-mixed powder and about 92° for the quasicrystal layers. The hardness and the contact angle with pure water for the Ti-Zr-Ni quasiscrystal layers tends to be higher than those for the sprayed layers obtained from the gently-mixed elemental powders.

4. Summary

Plasma thermal spryaing in air for the $Ti_{45}Zr_{38}Ni_{17}$ mechanically-alloyed powders produced several types of oxides and a binary intermetallic compound, but those prepared under a reduced pressure of argon produced an amorphous phase and a minor crystal phase. Subsequent annealing of the amorphous layers obtained after thermal spraying caused a transformation to an icosahedral quasicrystal phase and a minor fraction of a Ti_2Ni-type crystal phase. The Vickers hardness and the contact angle of the quasicrystal layers with pure water in air at room temperature were about 7 GPa and 92° respectively.

5. References

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