Process Optimization for Laser Gas Nitriding of Shape Memory NiTi alloys


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Introduction
Near-equatomic nickel-titanium (NiTi) alloy, which is well known for its unique shape memory and superelastic properties, have been widely used in various biomedical applications, such as cardiology, vascular stents, staple and knee joints [1-2]. However, from the perspective as a bio-metallic material, the relatively inferior wear resistance of NiTi is a big concern as it will increase the chance of releasing toxic Ni ion when the surface is worn-off in service [3-4]. Surface modification is therefore required to improve the wear resistance of NiTi.

One common approach to improve the wear resistance is to increase the surface hardness, i.e. the higher the hardness, the higher the wear resistance. Laser gas nitriding (LGN) was used in this study to increase the surface hardness of NiTi, given that it has the benefits of high efficiency, ease of control and automation, and high precision for the treatment location [5].

Experimental Details
Laser Gas Nitriding (LGN) process was performed using a 100W CW fiber laser (SP-100C-0013, SPI and A&P Co., Ltd) with a wavelength of 1091nm. The samples were carried out in a specially-designed gas chamber which was continuously discharged with pure nitrogen gas at a rate of 20 L/min. A series of experimental runs were conducted to determine the optimal set of processing parameters: laser power, scanning velocity and beam diameter to obtain the highest surface hardness. Table 1 shows the range of parameters varied in the LGN experiments:

Table 1. Choice of processing parameters

<table>
<thead>
<tr>
<th>Factor</th>
<th>Range of parameter</th>
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<tr>
<td>Output power</td>
<td>70 W – 90 W</td>
</tr>
<tr>
<td>Scanning velocity</td>
<td>300 mm/min - 900 mm/min</td>
</tr>
<tr>
<td>Beam diameter</td>
<td>0.4 mm – 0.6 mm</td>
</tr>
</tbody>
</table>

Results and Discussion
From the results of LGN experiments, the optimal parameter set was found to be 90 W output power, 300 mm/min scanning velocity, 0.4 mm laser beam diameter and 20 L/min nitrogen gas flow rate. The surface hardness of NiTi after LGN was determined by Vickers micro-hardness test provided that the thickness of TiN deposited on the surface was thick enough to avoid the substrate effect. The Vickers hardness method consists of indenting the test material with a diamond indenter, which is to form a right pyramid with a square base with 136° between opposite faces, the schematic diagram of Vickers hardness test is depicted in Figure 1.

Table 2. Vickers hardness values of laser treated surface and bare NiTi

<table>
<thead>
<tr>
<th>Laser treated surface (TiN)</th>
<th>Vickers Hardness (HV)</th>
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<tr>
<td>700 HV ± 68</td>
<td></td>
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<tr>
<td>Bare NiTi</td>
<td>360 HV ± 40</td>
</tr>
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</table>

The Vickers hardness results in Table 2 shows that the hardness of the laser-nitrided surface reached about 700 HV ± 68 which was nearly twice that of the bare NiTi. The increased hardness was due to the formation of the very hard nitride layer by LGN. The nitride formation mechanism can be represented by:

\[ \text{Ti} \rightarrow \alpha-\text{Ti} (N) \rightarrow \text{Ti}_2\text{N} \rightarrow \text{TiN} \]

Conclusions
In this study, an optimal set of laser parameters to deposit a TiN layer on NiTi were identified. The microstructural and mechanical properties of the layer were determined as follows:
1. The optimum parameter combination were 90 W (laser output power), 300 mm/min (laser scanning velocity), 0.4 mm (laser beam diameter) and 20 L/min (nitrogen gas flow rate).
2. A layer of TiN was formed on the surface of NiTi with the thickness about 50 μm to 60 μm. A dendritic phase could be observed in the nitried zone. The Vickers hardness of the TiN was about twice that of the bare NiTi.

References

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