Evidence of Surface Compression and Stability of Laser-peened Material without Coating

Laser peening without coating (LPwC) is an emerging surface enhancement technology. The effects of eliminating stress corrosion cracking (SCC) susceptibility and enhancing fatigue strength for metal materials have been demonstrated through various experiments and applications [1]. However, it still remains as an open question how the surface layer can be compressive despite the possible thermal effect of LPwC, where intense laser pulses directly irradiate the material surface [2].

The purpose of this study is to present substantial evidence showing that the surface after LPwC is compressive and the residual stress imparted by LPwC is stable under thermal loading. For this purpose, we have applied a constant penetration depth (CPD) method, which can provide relevant information on the surface residual stress, because the method enables us to control the X-ray penetration depth constant for a series of exposures with various ψ angles [3]. By combining this method with the high energy and high brilliance X-ray of SPring-8, the residual stress depth profile in the surface layer can be precisely evaluated in a non-destructive manner.

Preliminary experiments were conducted to prove the effectiveness of the CPD method with a 25 keV X-ray at beamline **BL19B2**. Figure 1 shows an example of the so-called $\sin^2\psi$ diagram obtained by a conventional ψ-goniometer method for high tensile strength steel (JIS SHY685) with a huge stress gradient. Since the residual stress is supposed to be proportional to the slope of the diagram, the result is strongly affected by the range of ψ angles used in the measurement. The $\sin^2\psi$ diagrams obtained by the CPD method for various penetration depths of the same sample are shown in Fig. 2. There is no ambiguity in deducing residual stress since the data for each penetration depth make an almost straight line. Through the preparatory experiments above, it was concluded that the CPD method could allow us to properly evaluate the residual stress depth profile in the surface layer non-destructively.

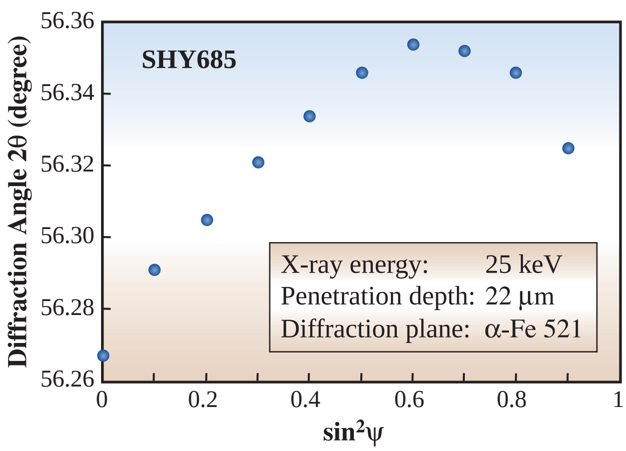

Fig. 1. $\sin^2\psi$ diagram obtained by conventional ψ-diffractometer method.

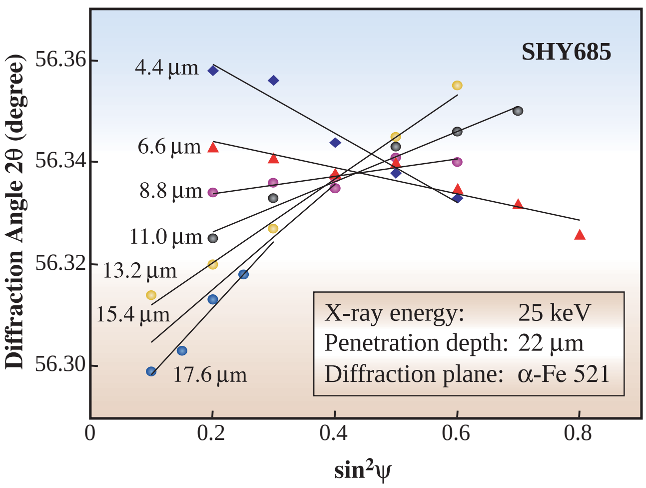

Fig. 2. $\sin^2\psi$ diagram obtained by CPD method.

LPwC was applied to samples of 20% cold-worked austenitic stainless steel (JIS SUS304). The conditions of laser peening were a 60 mJ pulse energy, a 0.7 mm spot diameter and a 70 pulses/mm^2 density. The residual stress depth profile was evaluated by the CPD method before, during and after heat treatment at up to 673 K. The resulting residual stress depth profiles are shown in Fig. 3. It is evident that the surface layer is compressive despite the direct irradiation of laser pulses to the surface in LPwC. The heat treatment somewhat reduced the residual stress; however, the overall distribution was quite stable. This kind of measurement using the same sample could not be realized without the CPD method with the high energy X-ray of SPring-8.

LPwC was also applied to a ceramic material. Since the residual stress distribution in the surface region largely affects the mechanical property of brittle materials such as ceramics, it is important to evaluate the depth profile without interference that might be introduced by machining or grinding. However, measuring the residual stress depth profile of ceramics is a difficult task because it is not easy to remove the surface layer due to its hardness. On the other hand, the density of ceramics is relatively low and consequently it makes the CPD method attractive for measuring the depth profile using a high energy X-ray that highly penetrates into ceramics.

Samples were prepared from finely ground Si_3N_4. LPwC was performed under conditions of a 40 mJ pulse energy, a 1.0 mm spot diameter and a 18 pulses/mm^2 density. The profiles of the ground and laser-peened samples were measured with 15 keV and 25 keV X-rays at BL19B2. The results obtained are shown in Fig. 4. Both profiles obtained at different X-ray energies well agree with each other. Because the laser peening conditions are much gentler than those for the metal material, the amplitude of compressive residual stress is relatively small and the depth is also shallow.

The strong evidence of surface compression on laser-peened SUS304 and Si_3N_4 without coating has been successfully obtained through the present experiments by the CPD method in conjunction with the high energy and high brilliance X-ray of SPring-8. The method is versatile and opens up new applications to many industrial materials and components.

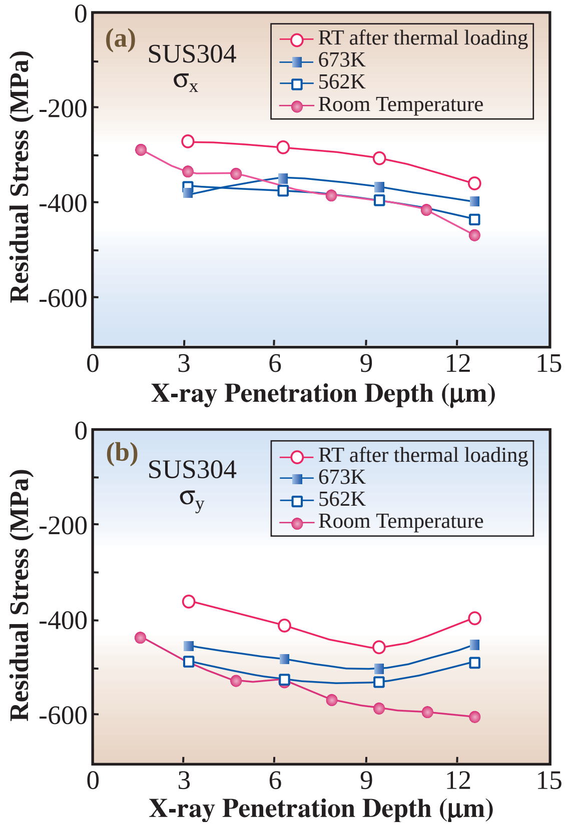

Fig. 3. Residual stress depth profile of laser-peened SUS304 obtained by CPD method.

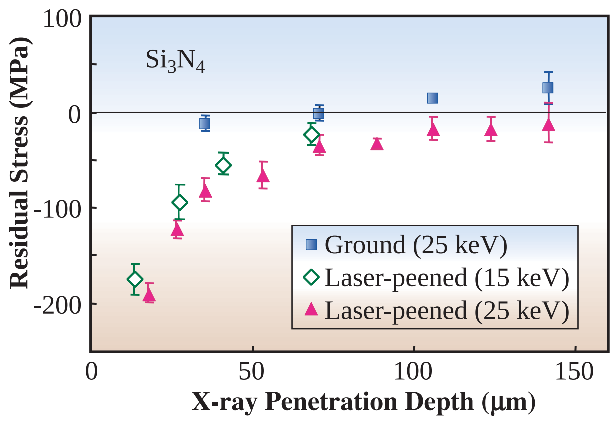

Fig. 4. Residual stress depth profile of laser-peened Si_3N_4 obtained by CPD method.

Yuji Sano[a,*] and Koichi Akita[b]

[a] Toshiba Corporation
[b] Musashi Institute of Technology

*E-mail: yuji.sano@toshiba.co.jp

References

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