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Enhancement of the punch pin durability induced by the PVD coating in production process of the automotive inner pipe†

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Abstract

This experimental studies were carried out in order to understand the effects of the PVD coating and the UNSM treatment of HSS55 (high speed steel 55) during the production of the automotive inner pipe by the plastic deformation of S45C. The field test and the SEM images revealed that the PVD coating is necessary in spite of the high compressive residual stresses which were formed at the head of a punch pin. Upon the application of the AlCrN coating with the UNSM treatment the productivity and reliability of a punch pin had improved more than about 2.6 times compared to that of the TiN coating without the UNSM treatment. It is likely that the improvement is caused by the decreased stress concentration factor by the 'wrapped in oxides' inside of an abrasion pit. The abrasion pits were mostly generated within range of 5% ~ 50% of the diameter ratio from the end of a pin and reached the maximum value about 17% from the end of a pin.

Keywords: Physical vapor deposition (PVD); Durability; Punch pin; Ultrasonic nanocrystal surface modification (UNSM); Abrasion pit

1. Introduction

Over the last few decades, the PVD plasma ceramic coating (such as the TiN, TiAlN, and AlCrN) [1-6] for the surface modification [such as the UNSM (Ultrasonic Nanocrystal Surface Modification)] [7-13] has been studied rigorously because of its advantages which include the cost reduction of machinery parts, an improvement in quality, and the mass production with the energy efficiency.

It has been reported that the fatigue behavior and mechanical characteristics with the development of surface modification [7-13] can be improved by employing the ultrasonic shot peening and the UNSM [7]. The productivity and the manufacturing cost of the punch pin made of HSS55 (high speed steel 55) is an important issue due to its tool life.

This study is planned to gain the information on the surface wear damage and wear characterization [13-15] which is induced by the PVD coatings (such as the TiN, TiAlN, and AlCrN coatings) along with the UNSM treatment on HSS55. The results of this study could be applied for the manufacture of the automotive inner pipe which is made of S45C.

The durability of a punch pin and the life time of tools are studied statistically based on the quantitative data obtained by abrasion pit densities and the SEM (Scanning Electron Microscopy) images.

2. Experimental methods

The punch pin subjected to the cold forging was studied to understand the cause of wear damage. Fig. 1 shows the schematic diagram of the cold forging process of the automotive inner pipe by the punch pin made of HSS55. A material (S45C) is forged into an inner pipe and then the head area (marked H in Fig. 1) of a punch pin is subjected to the severe wear.

The SEM image was used in order to understand the wear damage on the surface of the punch pin during the PVD plasma ceramic coating such as the TiN, TiAlN, and AlCrN along with the UNSM treatment as shown in Fig. 2 [7].

3. Test results and discussions

3.1 The variation of surface characteristics of a punch pin

Fig. 3 shows an example and the dimension of a punch pin. After the UNSM treatment [7, 8], the variation of the surface roughness (Ra) on the head has been improved [7] about 3.7 times compared to the non-treated condition. Before the

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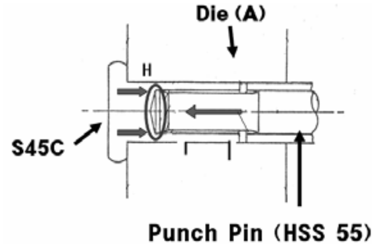

Fig. 1. Schematic diagram of the cold forging process by a punch pin.

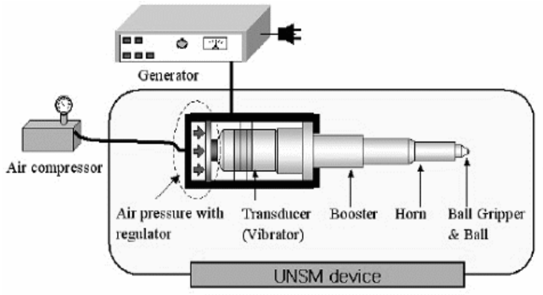

Fig. 2. Schematic diagram of the UNSM treatment device.

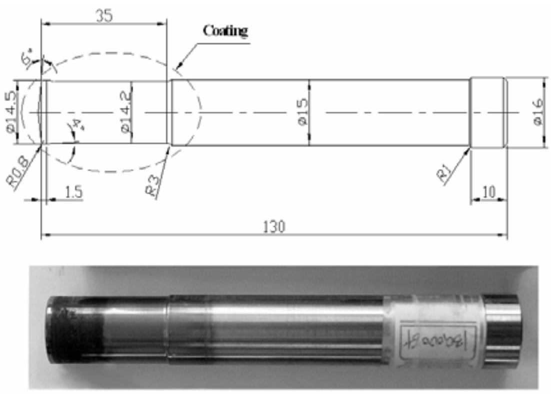

Fig. 3. An example and the dimension of a punch pin.

UNSM treatment Ra was 0.26 μm and it has been changed to 0.07 μm after the UNSM treatment. The hardness of a punch pin is 59.3 HRC after the machining, and it becomes 65.3 HRC after the UNSM treatment.

Table 1 shows the assumed schematic diagram of 'wrapped in oxides' formation mechanism in the abrasion pit during to the PVD coatings and the UNSM treatment. Three stages including the early stage, the intermediate stage, and the final stage were described.

3.1.1 *The surface characteristics of the TiN coatings (before the UNSM treatment)*

Fig. 4 is a photograph of the right edge of a TiN-coated punch pin after the usage of 50,000 times. Although the punch pin has been used 50,000 times in the plastic process, it was hard to see a trace of abrasion on the top of a TiN-coated punch pin, except the boundary area (about 0.6-2.4 mm from the edge) of a pin. When magnified the squared area of Fig. 4,

Table 1. Schematic diagrams of 'wrapped in oxides' mechanism in abrasion pit.

	The early stage	The intermediate stage	The final stage
Before UNSM TiN coating			
After UNSM TiN coating			
After UNSM TiAlN coating			
After UNSM AlCrN coating			

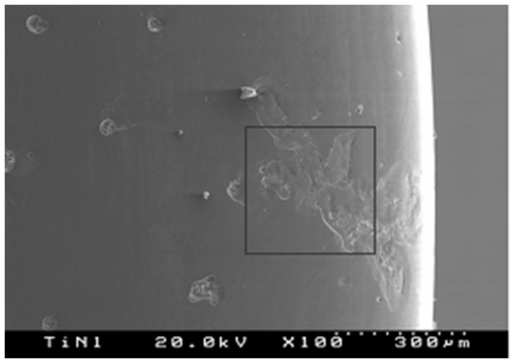

Fig. 4. An example of the edge of a TiN-coated punch pin without the UNSM treatment after the usage of 50,000 times.

a TiN thin film was locally broken by the wearing on the punch pin.

A result of the EDS (Energy Dispersive X-ray Spectrometer) analysis indicates that the main ingredients of HSS55 are Fe, W, Cr, Co, and V. In other words, the main composition of the punch pin was detected by the EDS, because 4 μm TiN coating was broken away and became an abrasion pit. An abrasion pit with a width of about 8-12 μm and a depth of 4 μm was characterized in this study.

Fig. 5 shows the wearing trace consists of 4 abrasion pits and Fig. 6 is the side view of Fig. 4. The bold arrow in Fig. 6 represents the center of the punch pin, and the edge of this pin corresponds to the bright parts of the sample in Fig. 4. The slick area in Fig. 6 (except the top and bottom regions) is the side area of the punch pin's head, and Fig. 6 shows the small surface wearing and traces which is the result of the "wrapped in oxides" as shown in Table 1.

Fig. 7 is the analysis of the squared area in Fig. 4 by the EDS and the results indicate that oxides, Ti and Fe are the main components.

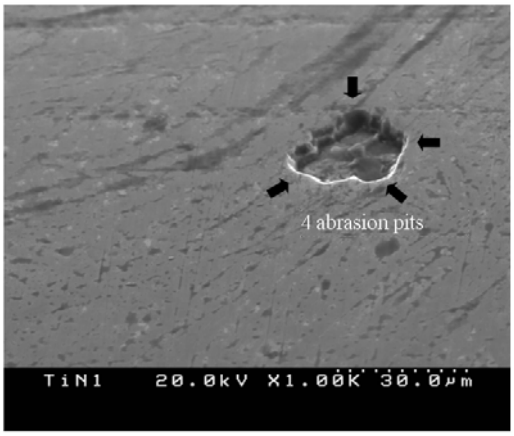

Fig. 5. An example of a wear trace consists of 4 abrasion pits generated in the squared area of Fig. 4.

3.1.2 The surface characteristics of the UNSM treatment (before the PVD coating)

Fig. 8 is the right part of a punch pin treated by the UNSM Technology [7, 8] without the PVD coating.

Even though this pin has been used only 5,000 times, the edge of the pin is experiencing a significant wearing between 0.1 mm to 0.5 mm from the edge. It is remarkable that the wearing phenomenon as shown in Fig. 8 is more severe than that of a TiN-coated punch pin as shown in Fig. 4.

Fig. 9 is the analysis of the squared area in Fig. 8 by the EDS and the results indicate that oxides, Fe, and Co are the main components. Fig. 10 is the side view of Fig. 8 which shows the wear traces. The wear traces A and B are considered to be generated during the plastic process, because there is no hard surface layer like a TiN coating.

The effects of the UNSM treatment disappeared in the case of non-coating of the PVD. It is verified that a ceramic coating is very important in the field of the plastic process.

3.1.3 The surface characteristics of the TiN coating (after the UNSM treatment)

The punch pin was coated with TiN, AlCrN, and TiAlN after the UNSM treatment, respectively and it was tested to obtain its wear characteristics. The TiN coating was partially worn out as in the sample in Fig. 5. The wear traces was not observed at the most of the head except the end of the punch pin (0.6 mm ~2.4 mm) after the usage of the 50,000 times.

3.1.4 The surface characteristics of the AlCrN coating (after the UNSM treatment)

The AlCrN-coated pin with the UNSM treatment after the usage of 130,000 times created more abrasion pits than that of the TiN-coated one. The center of the pin was also sleek. Fig. 11 shows the left side of the head on which AlCrN is coated. This figure shows the examples of 'peel-out' (mark on 'O') type and 'wrapped in oxides ' (mark on 'U') among abrasion pits as shown in Table 1. 'U' type is shown frequently rather than 'O' type.

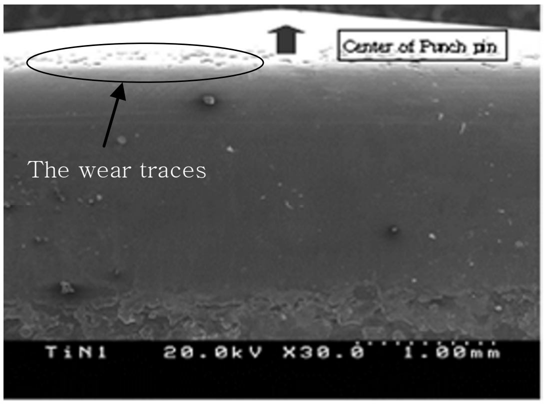

Fig. 6. Side view of Fig. 4 and shows the wear traces.

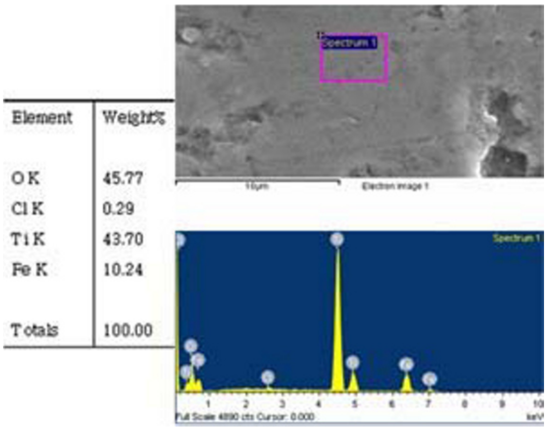

Fig. 7. Analysis by the EDS at the center of Fig. 4.

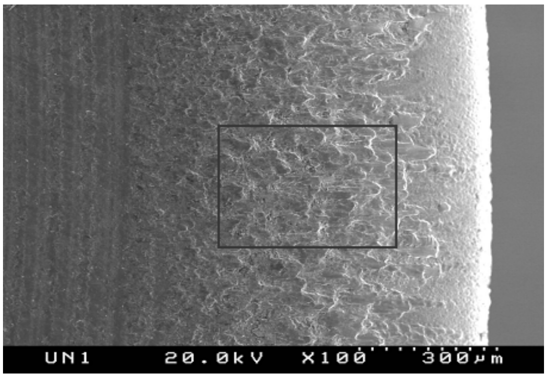

Fig. 8. An example of the edge of a PVD-noncoated punch pin with the UNSM treatment after the usage of 5,000 times. The right part of a punch pin shows the wear traces.

The abrasion pit produced during the AlCrN plasma coating process (see Fig. 12) was filled with oxides more easily compared to that of the TiN or the TiAlN coating.

Also to estimate the life time of the tools, in the field, carefully checked the inside of the inner pipe by observing the inside with the magnifier. The AlCrN-coated tool has fewer abrasion pits or oxides in the inner pipe compared to that of the TiN or the TiAlN coating.

This property of an abrasion pit, so called ‘wrapped in ox-

Element	Weight%
O K	21.10
Cl K	0.60
Fe K	77.66
Co K	0.64
Totals	100.00

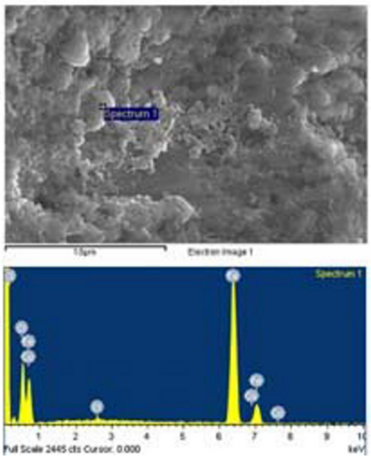

Fig. 9. Analysis by the EDS at the center of Fig. 8.

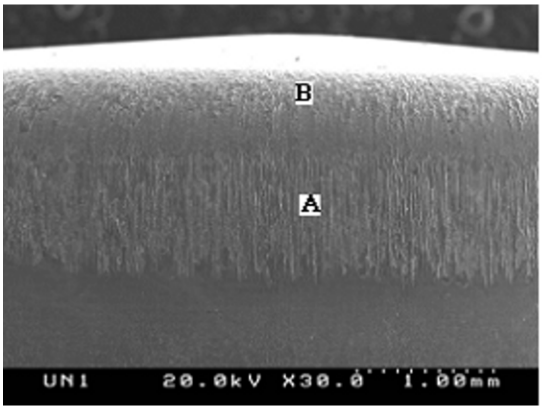

Fig. 10. The side view of Fig. 8 shows the wear traces.

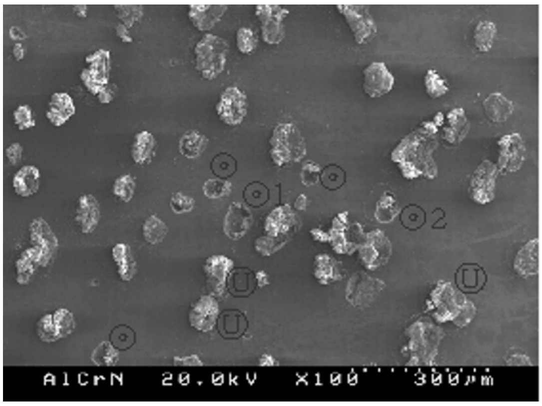

Fig. 11. An example of abrasion pits initiated on the edge of the AlCrN-coated punch pin after the usage of 130,000 times.

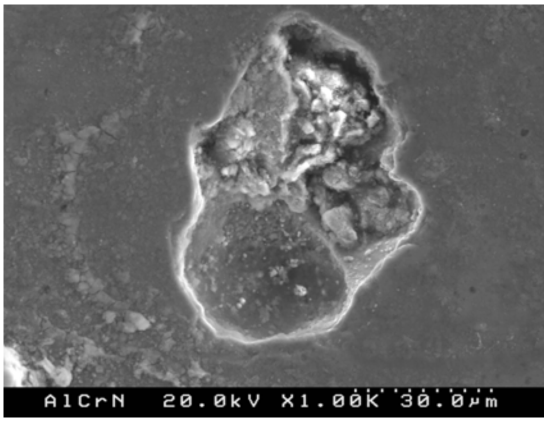

Fig. 12. An example of abrasion pits: 'wrapped in oxides'.

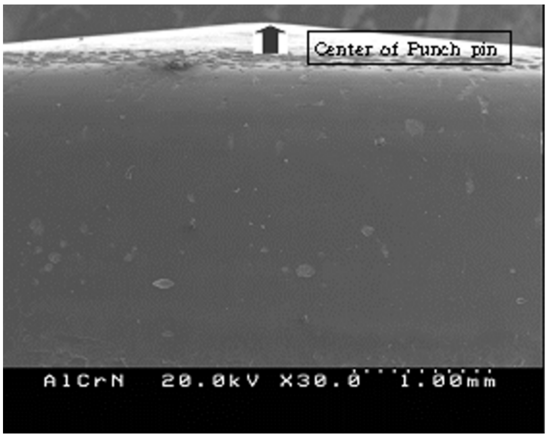

Fig. 13. A side view of the AlCrN-coated punch pin.

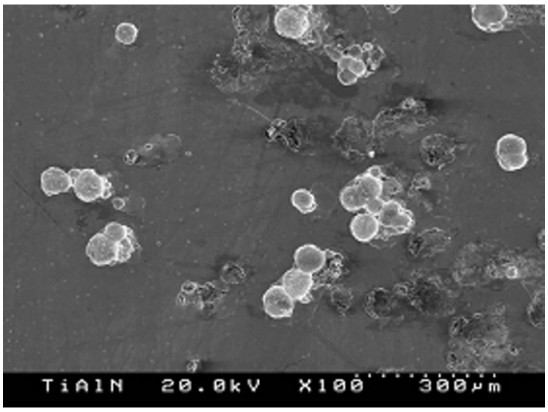

Fig. 14. An example of abrasion pits initiated on the edge of the TiAlN-coated punch pin after the usage of 80,000 times.

ides', reduces the stress concentration of an abrasion pit and lengthens the punching tool's life. Fig. 13 shows the side view of the AlCrN-coated pin, a sleek surface and the wear traces.

3.1.5 The surface characteristics of the TiAlN coating (after the UNSM treatment)

The surface characteristic of the TiAlN coating after the UNSM treatment at the SEM macro-photography showed remarkably distinctive 'peel-out' phenomenon compared to those of the TiN coating (see Fig. 4) and the AlCrN coating (see Fig. 11). In particular, the generation of continuous 'peel-out' phenomenon can be observed near the punch pin (1 mm from the end of a pin).

Fig. 14 is an example of abrasion pits initiated on the edge of the TiAlN-coated punch pin after the usage of 80,000 times. There are three types of the abrasion pit, as shown in Table 1,

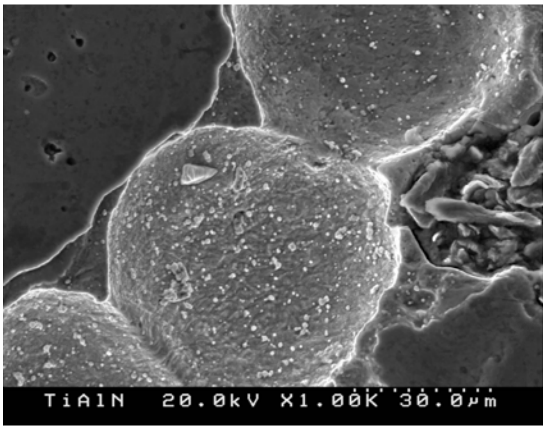

Fig. 15. An example of minute oxides formed inside the abrasion pit of the TiAlN-coated punch pin.

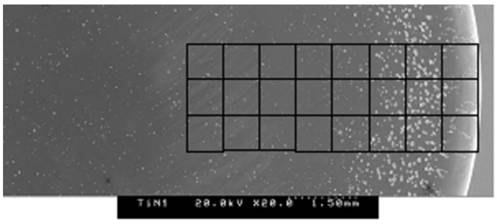

Fig. 16. An example of a net of 2 mm meshes at the mosaic macro-photography.

in the case of the TiAlN coating. The first type is the 'wrapped in oxides' with half, the second type is the 'filled in oxides fully', and the third type is the 'peel-out' totally with the observable bottom. Fig. 15 is an example of the early stage of 'wrapped in oxides' and shows the minute oxides formation inside an abrasion pit.

3.2 The number of an abrasion pit and the variation of the density

A lot of abrasion pits are formed on the top of the punch pin after the plastic process. The number of pits is counted at the mosaic macro-photography using a net of 2 mm meshes and analyzed the density as a function of the distance (from the center to the edge). An abrasion pit is defined as a wear trace with the width of 8 μm ~ 12 μm and the depth of 4 μm.

Fig. 16 shows an example of a case of the most abounds with an abrasion pit formed during the plastic process. Fig. 17 shows the variation of its densities as the function of distance and the coating conditions. The data is obtained at a net of 2 mm meshes. The bold line in Fig. 17 indicated the variation of mean abrasion pit density of six punch pins.

The abrasion pits were mostly generated between 0.6 mm to 2.4 mm from the end of a pin and reached the maximum value of 1.2 mm. Therefore the most serious 'peel-out' phenomenon occurred around 1.2 mm from the end of the punch pin in this study.

If we change the distance from the end of a pin into the diameter ratio which divided by its radius as shown in Fig. 17,

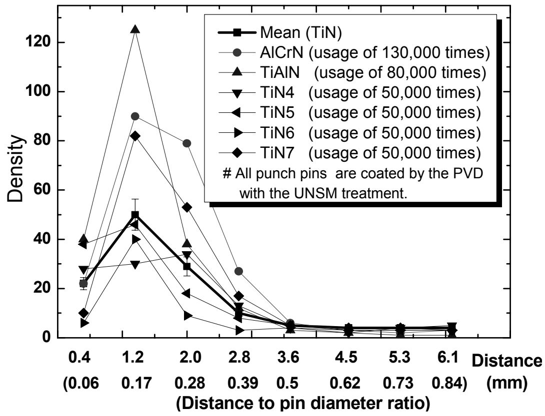

Fig. 17. Variation of the abrasion pit density according to the distance (distance to pin diameter ratio) and coating conditions.

the abrasion pits were only generated with in the range of 5-50% of the diameter ratio, and the maximum value is about 17% from the end of a pin.

4. Conclusions

The experiments presented in this paper are planned to obtain the data and information on the effects of the PVD coating and the UNSM-treatment of HSS55 during the production of an automotive inner pipe by the plastic deformation of S45C. Based on the field tests and the SEM observation, we concluded that the compressive residual stresses are formed at the head of the punch pin by the UNSM treatment.

Upon the application of the AlCrN coating with the UNSM treatment (the usages of about 130,000 times), the productivity and reliability of a punch pin have been improved more than about 2.6 times compared to that of the TiN coating without the UNSM treatment (the usages of about 50,000 times). It is likely caused by the decreasing of stress concentration factor of abrasion pits by the 'wrapped in oxides' inside of it.

The abrasion pits are mostly generated within the range of 5-50% of the diameter ratio from the end of a pin, and the maximum value is about 17% from the end of a pin.

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SEM (Hitachi S-4200) observation.

References

[1] C. M. Suh, M. H. Lee, B. W. Hwang and S. H. Kim, Damage Behavior in Ceramic Plasma-Coated and Uncoated Glass with Steel-Ball Impact, *J. Am. Ceram. Soc.,* 86 (7) (2003) 1220-1222.

[2] C. M. Suh, B. W. Hwang and K. R. Kim, Effect of ceramic coating thickness on residual stress and fatigue characteristic of 1Cr-1Mo-0.25V steel, *Int. J. of Modern Physics B*, 16 (1&2) (2002) 181-188.

[3] F. Zhou, C. M. Suh, S. S. Kim and R. I. Murakami, Tribological behavior of CrN coating on aluminum alloys deposited by arc ion plating, *J. of Materials Science (JMR)*, 17 (12) (2002) 3133-3138.
[4] C. M. Suh, F. Zhou, S. S. Kim and R. I. Murakami, Sliding wear behavior of TiN- and CrN-coated 2024 aluminum alloys against an Al_2O_3 ball, *Tribology Letter*, 13 (3) (2002) 173-178.
[5] C. M. Suh, B. W. Hwang and R. I. Murakami, Behaviors of residual stress and high-temperature fatigue life in ceramic coatings produced by PVD, *Materials Science & Engineering*, A343 (2003) 1-7.
[6] C. M. Suh, S. H. Kim and D. Y. Suh, Experimental study of the impact damage on an Al_2O_3 coated glass under stress, *Int. J. of Modern Physics B*, 20 (Nos.25-27) (2006) 4529-4534.
[7] I. H. Cho, G. H. Song, C. M. Suh and Y. S. Pyoun et al., Nano Structured Surface Modification of Tool Steel and its Beneficial Effects in Mechanical Properties, *J. of Mechanical Science and Technology*, 19 (11) (2005) 2151-2156.
[8] Y. S. Pyoun and C. M. Suh, et. al., 2008, The ultrasonic nano-crystal surface modification technology and it's application to improve fatigue strength, wear resistance, and service life & energy efficiency of bearings, *Proceeding of ICSP-10, Tokyo, Japan*, (2008) 416-421.
[9] S. Mader and F. Klocke, Fundamentals of the Deep Rolling of Compressor Blades for Turbo Aircraft Engines, *Proc. 9th Int. Conf. on Shot Peening, Technology Transfer Series*, (2005) 125-130.
[10] C. S. Montross, T. Wei, L. Ye, G. Clark and Y. W. Mai, Laser shock processing and its effects on microstructure and properties of metal alloys: a review, *Int. J. of Fatigue*, 24 (10) (2002) 1021-1036.
[11] I. Nikitin, I. Altenberger, H. J. Maier and B. Scholtes, Mechanical and thermal stability of mechanically induced near-surface nanostructures, *Materials Science and Engineering*, A403 (2005) 318-327.
[12] R. K. Nalla, I. Altenberger, I. Noster, G. Y. Lui, B. Scholtes and R. O. Ritchie, On the influence of mechanical surface treatments - deep rolling and laser shock peening - on the fatigue behaviour of Ti-6Al-4V at ambient and elevated Temperatures, *Materials Science and Engineering*, A355 (2003) 216-230.
[13] I. Altenberger, B. Scholtes, U. Martin and H. Oettel, Cycle deformation and near surface microstructures of shot peened or deep rolled Austenitic steel AISI 304, *Materials Science and Engineering*, A264 (1999) 1-16.

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