DENKI-SEIKO (Electric Furnace Steel), vol. 85 (2014), No.1, p39 - 46
Technical Data

Life Evaluation of Surface Treatments of Mold in Cold Working of High Strength Steel

Shigeki Higuchi, Tetsuya Masuda, Takayuki Shimizu,
Takashi Matsuno, and Koichi Sato

1. Preface

In recent years, demand for reducing automotive weight by improving fuel efficiency to prevent global warming has increased. Therefore automotive parts made from the high tensile strength steel sheets, over 340 MPa class, are increasing[1)]. The weight percentage of high strength automotive parts in some special cars has increased from 40% in 2004 to about 60% currently[2)3)]. 1200MPa class ultra-high strength steel sheets have already been developed, and higher strength steel sheets are also the object of studies now.

In the meantime, interest in the die life of the cold press working for high strength automotive parts is increasing. Opportunities are increasing for the surface treatment application to these cold press working die to prevent wear and galling[4)]. Therefore many kinds of surface treatment have been developed and commercialized for pressing high strength steel sheets. Daido Steel has developed new high performance PVD (Physical Vapor Deposition) coating “HT-CERAC” in cooperation with Daido Die & Mold Solution, Nissin Electric and Nippon ITF[5)]. HT-CERAC coating is designed for prevention of galling, and has reached the less defects surface by optimizing the coating conditions compared with conventional coatings. HT-CERAC has achieved longer die service life than those of conventional coatings because of high galling resistance under evaluation with our original 780MPa class steel sheets bending test and 1180MPa class steel sheets deep drawing test in cooperation with Toyohashi University of Technology[5)].

In this paper, punches service lives of various coatings, PVD, CVD (Chemical Vapor Deposition) and TRD (Thermal Reactive Deposition) process, by the establishment of a piercing test using a progressive die have been evaluated. Their cost-effectiveness has also been calculated along with effects of work sheet strength and clearance on punches service lives have been investigated.

2. Test conditions

2.1 Piercing test conditions

Figure 1 shows the schematic diagram of piercing test. Punches were tested with the clearance of 3%t (3% of work sheet thickness) and with the inclination of work sheet against the punch top surface of 3 degree without lubricant in order to accelerate punch damage in short term. To investigate effect of clearance, the both 3%t and 6%t conditions have been tested with 1180MPa class sheets.

The crank press, 150tnf high flex press made by Aida Engineering, was used for the test. Press speed were set to 50 to 55 SPM. SPM stands for shots per minute.

Work sheets were 590, 980 and 1180 MPa class high strength cold-rolled non-plated steel with thickness of 1.6 mm made by Nippon Steel. The die material was DC53, JIS SKD11 modified steel grade, made by Daido Steel. Its hardness was 62 HRC.

Coating conditions are shown in Table 1. Two punches per condition were tested. HT-CERAC with nitriding was also tested. Figure 2 shows the optical micrograph and the hardness distribution near the surface of nitriding+HT-CERAC. The nitride layer had no compound layer at the boundary between coating and substrate. Its maximum hardness was about 1100 HV and the case depth was about 50 μm. As shown in Figure3, the punch edge was chamfered to prevent chipping.

Piercing test can evaluate 8 punches at the same time. Punch positions are shown in Figure4. Every punch position was changed every 1000 shots to reduce stress variation dependence on punch positions.

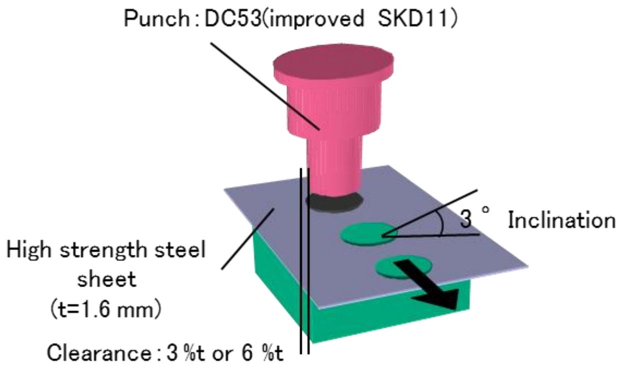

Fig. 1. Schematic diagram of pierce processing test.

Table 1. Test coating. *DDMS: Daido Die & Mold Steel Solution, Co., Ltd.

No.	Surface treatment
1	VC (TRD process): Company A
2	TiC (CVD process): Company B
3	TiN (PVD process): HT-CERAC by DDMS*
4	Nitriding + HT-CERAC

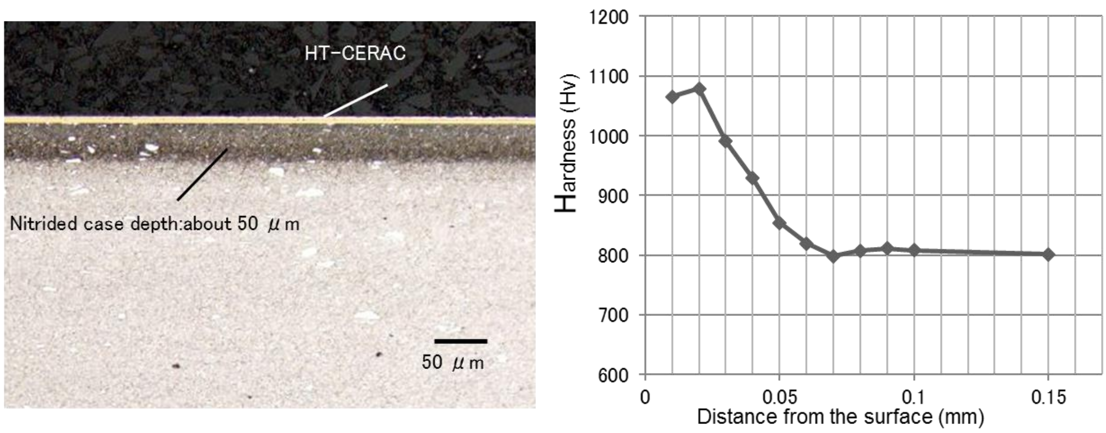

Fig. 2. Nitriding quality of nitriding+HT-CERAC.

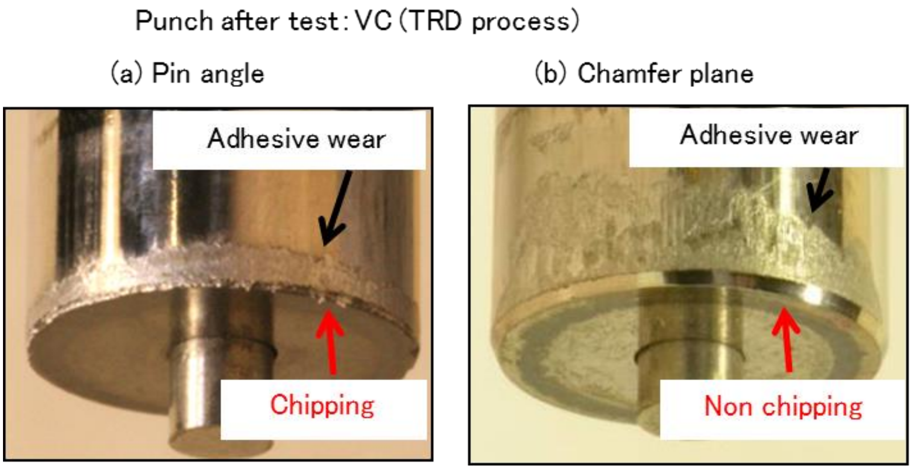

Fig. 3. Difference in damage morphology with shape of punch tip.

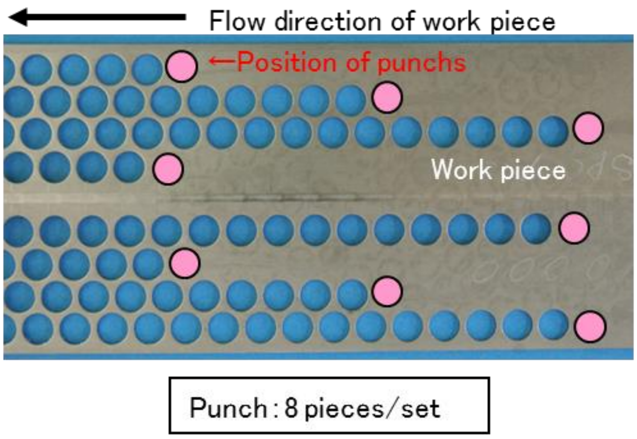

Fig. 4. Position of punches.

2.2 Evaluation of punch service life

Table 2 shows test conditions. The sampling of skeleton sheet that was pierced work sheet and punch appearance photographs were taken at the sampling timing described in Table 2.

The punch service life was defined whether there was a streak scratch due to galling on the burnishing surface of skeleton sheets or not as shown in Figure 5.

Each coating cost-effectiveness was calculated by punches service lives per cost of making coated punches, and they were evaluated by relative comparison with TRD coated punches. Cost of making punch include material cost, machining cost, heat treatment cost, coating & nitriding cost and polishing cost before and after coating.

Table 2. Test conditions.

	Steel sheet type	Clearance	Max test shots	Sampling of test	Photograph of appearance
A	590 MPa (t=1.6 mm)	3 %t	20000	1, 10, 200~2000 shots: every 200 shots, 2000 shots~: every 2000 shots	every 2000 shots
B	980 MPa (t=1.6 mm)	3 %t	10000		
C	1180 MPa (t=1.6 mm)	3 %t	2000	1, 10, 100~1000 shots: every 100, 1500, 2000 shots	every 500 shots
D	1180 MPa (t=1.6 mm)	6 %t	7000	10 shots, 1000~ 7000 shots: every 1000 shots	every 2000 shots

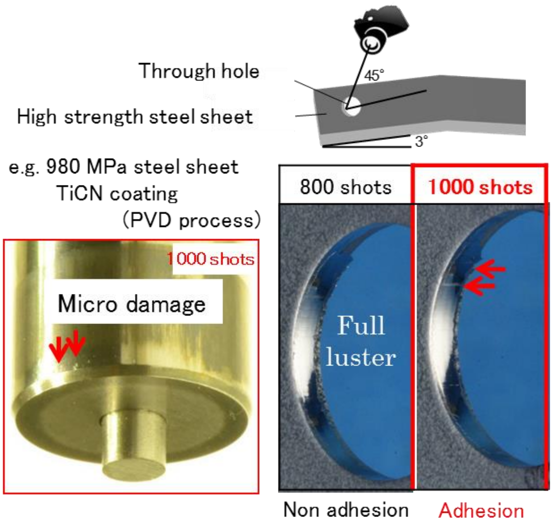

Fig. 5. Evaluation of punch life.

3. Results and discussion

3.1 Punch failure mode and effect on burr height

Figure 6 shows appearance photographs of punches coated with TiC by CVD process and VC by TRD process after test shots. Both two coated punches had no chipping at edge. However there were galling at positions indicated by arrows on photographs and galling area were increased with numbers of shots.

Appearance photographs of punches at 1000 shots with each work sheet conditions are shown in Figure7. With an increase in the strength of steel sheets, galling area were increased.

Figure 8 shows the burr height of the skeleton at each shots tested with 590 and 980 MPa class strength sheets. The galling area were increased with increasing numbers of shots. However, relationship between burr heights and numbers of shots were unable to be determined.

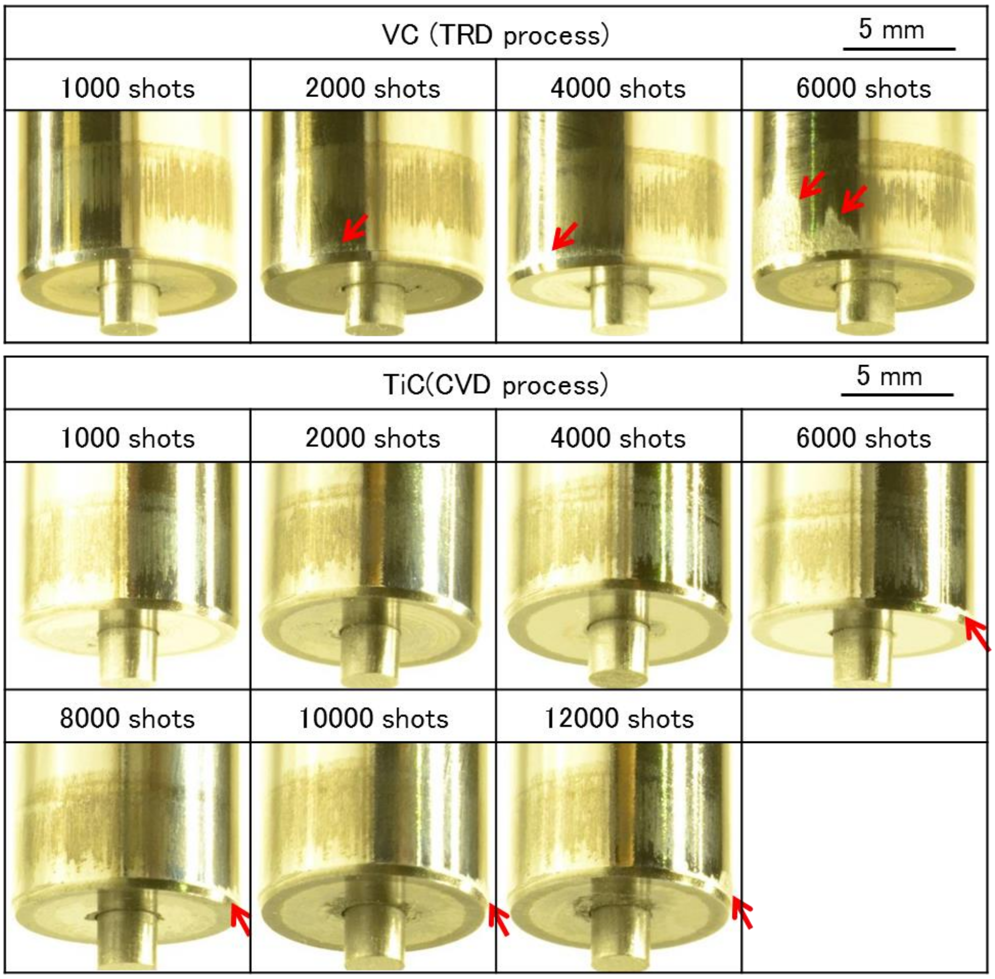

Fig. 6. Punch appearance of VC and TiC in 590 MPa high strength steel.

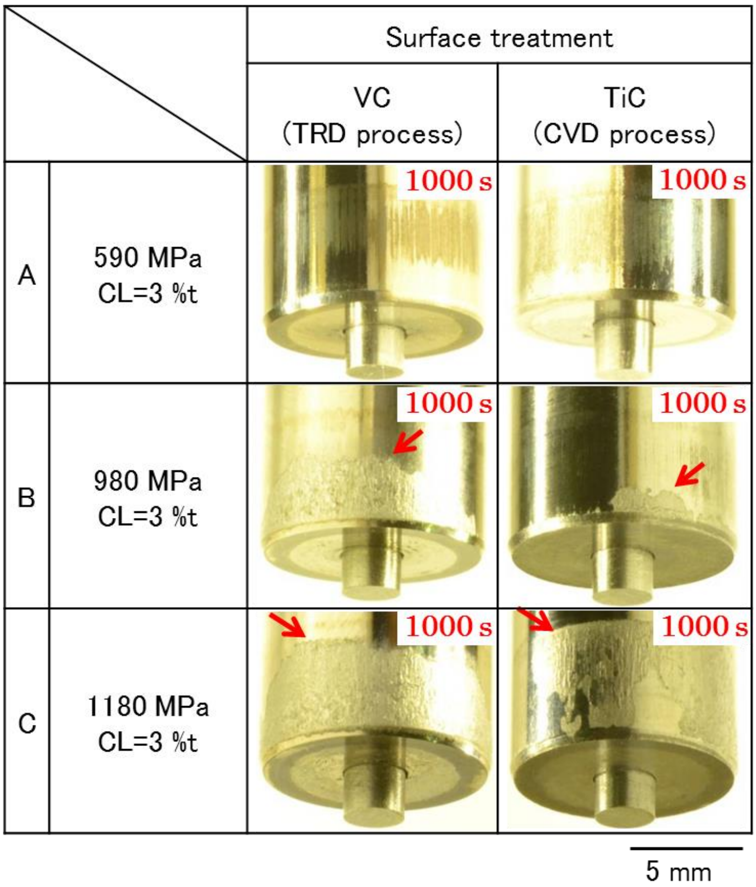

Fig. 7. Influence of steel strength to the adhesive wear.

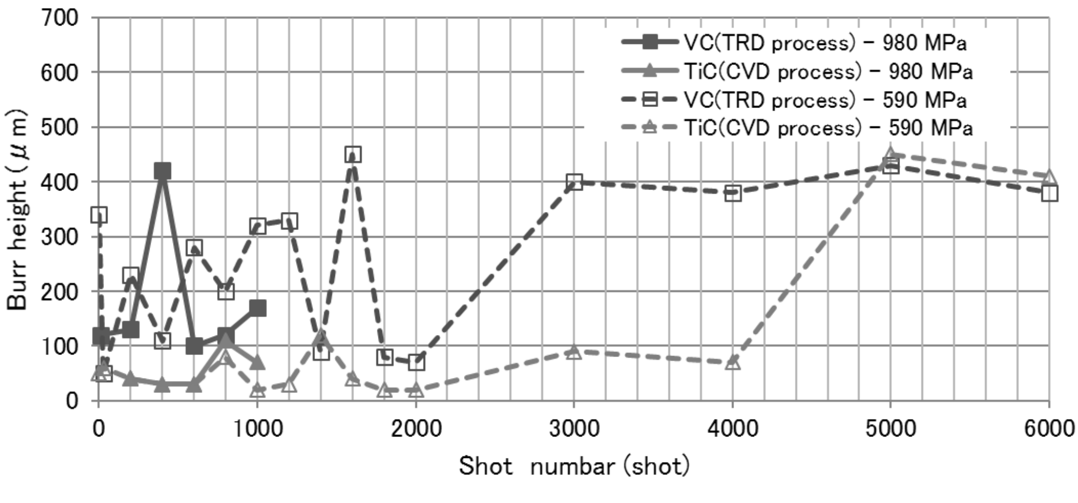

Fig. 8. Burr height of each shot in 590 MPa and 980 MPa.

3.2 The punch service life and the cost-effectiveness

3.2.1 Comparison with HT-CERAC, CVD coating and TRD coating

Results of punch service life are shown in Figure9. The service lives of HT-CERAC and CVD coated punches are longer than TRD coated punches at the every work sheet strength condition.

By comparing results under the same clearance condition, in case of HT-CERAC, the 980 MPa class sheet result was about 1/9 times shorter than that of the 590MPa class sheet result, and 1/22 times shorter in case of CVD coating. Therefore HT-CERAC was better coating for keeping service life compared to CVD coating. The result of 1180MPa class sheet was about 1/30 times shorter than the 590 MPa class sheet in case of both two coating conditions. Because of these service lives were too short, merits could not be determined.

By comparing results under the same work sheet strength, the 6%t result of CVD coating punch was about 6 times longer than that of the 3%t result and the result of HT-CERAC coating was about 10 times longer. HT-CERAC punches have about 1.5 times longer service life compared to CVD coating ones. Results of 1180 MPa class sheets and 6%t condition were better than 980 MPa class sheets and 3%t condition results on both two coating punches.

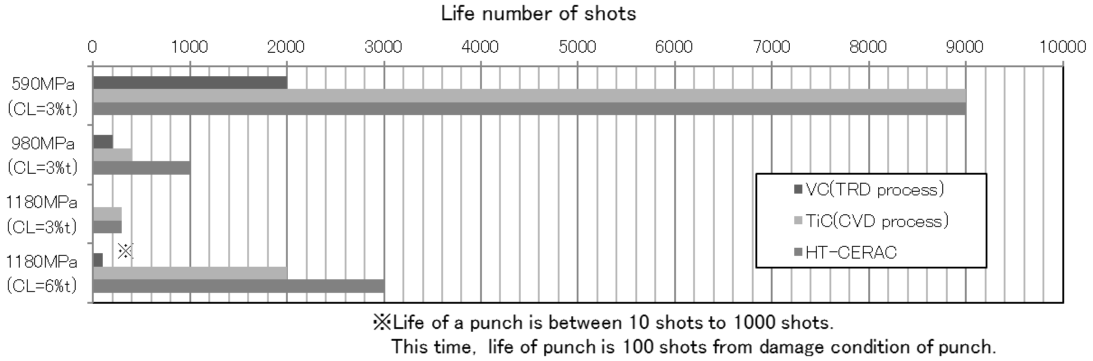

Fig. 9. Punch life comparison of HT-CERAC.

Figure 10 shows punch appearance photographs of each condition. The failure mode of HT-CERAC punches are only galling, not chipping as well as CVD and TRD coating punches. Positions of galling on the every punch were nearly the same.

The cost-effectiveness is shown in Figure11. Values are relative ones assuming the cost of TRD coated punch is set to 1. Cost-effectiveness of HT-CERAC and CVD coating punches were 2 to 5 times higher than TRD coated punch on 590 and 980 MPa class sheet conditions. Additionally, it was over 20 times more effective on the 1180 MPa class sheet condition. Therefore HT-CERAC and CVD coating have high cost merit as piercing punches of high strength sheets compared with TRD coating.

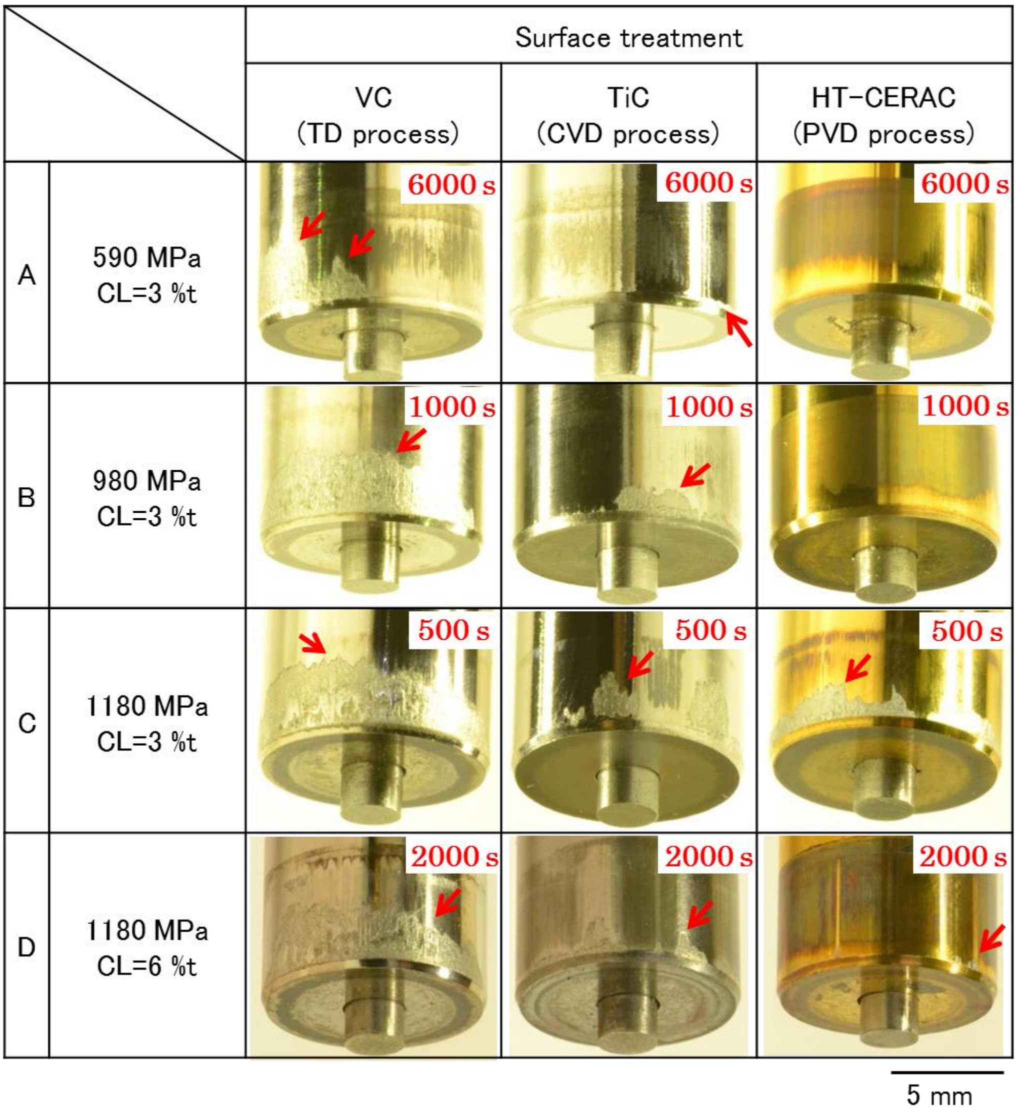

Fig. 10. Punch appearance comparison of HT-CERAC.

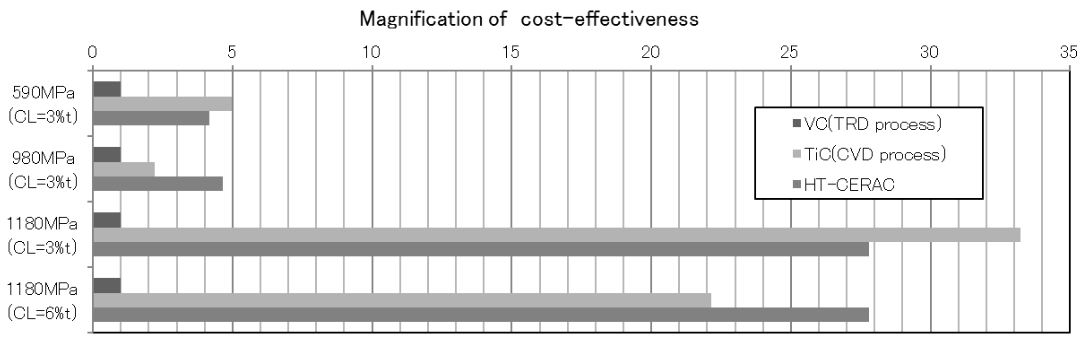

Fig. 11. Cost-effectiveness comparison of HT-CERAC coated punch.
(Cost-effectiveness of VC coated punch = 1)

3.2.2 The effect of nitriding under PVD coating

PVD process are treated at 500℃ and lower. Otherwise, CVD and TRD process are treated over 1000℃. Therefore PVD process can be treated on nitrided substrates without nitriding quality loss. This is the reason why nitriding+HT-CERAC was included in this test.

Figure 12 shows the service life comparison including nitriding+HT-CERAC punch results. The service life of nitriding+HT-CERAC punches are 1.5 to 3 times higher than HT-CERAC punches. Although HT-CERAC service life was almost same as CVD coating one, nitriding+HT-CERAC service life was clearly longer than CVD coating one under every test condition. However the effect of work sheet strength on nitriding+HT-CERAC service lives with the same clearance condition was almost same as HT-CERAC (non-nitriding). The rate of decreasing service life with increasing the work sheet strength were: 980 MPa class sheet result was about 1/5 times shorter than 590 MPa class sheet result and 1/40 times shorter than 1180MPa class result. The effect of the clearance on the nitriding+HT-CERAC service life with 1180 MPa sheet condition was almost same as HT-CERAC (non-nitriding). The 6%t condition result was about 10 times longer than 3%t result.

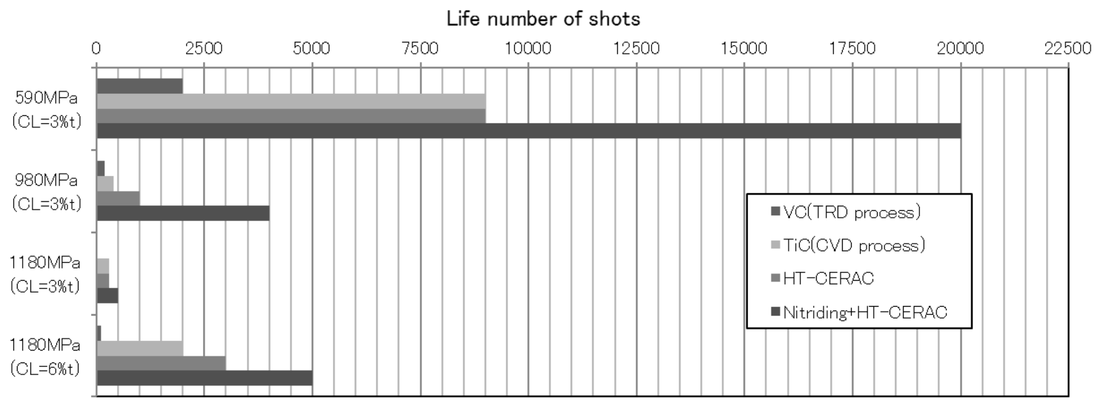

Fig. 12. Punch life comparison of nitriding+HT-CERAC.

Punch appearance photographs of nitriding+HT-CERAC and HT-CERAC (non-nitriding) are shown in Figure13. The positions of galling on punches were same with or without nitriding.

Figure 14 shows the cost-effectiveness that is a relative value assuming the cost of TRD coated punches is set to 1. The cost-effectiveness of nitriding+HT-CERAC was about 8 times more effective than TRD coating on the 590 MPa class sheet condition, about 16 times more on the 980 MPa class sheet condition and about 40 times more on the 1180 MPa class sheet condition. The cost-effectiveness increased with increasing work sheet strength. These values were better than HT-CERAC (non-nitriding) on every work sheet strength condition.

Figure 15 shows the cost-effectiveness that is a relative value assuming TRD coated punch cost with 590 MPa class sheet condition is set to 1. The cost-effectiveness of nitriding+HT-CERAC punch with 980 MPa class sheet condition and 1180 MPa class sheet & 6%t condition were better compared to TRD coated punches with 590 MPa class sheet condition. From this result, coating punches for 980 MPa and 1180 MPa class sheets piercing process can be made with the same cost as TRD coated punches for 590 MPa class sheets by applying nitriding+HT-CERAC and adjust the clearance between dies and punches.

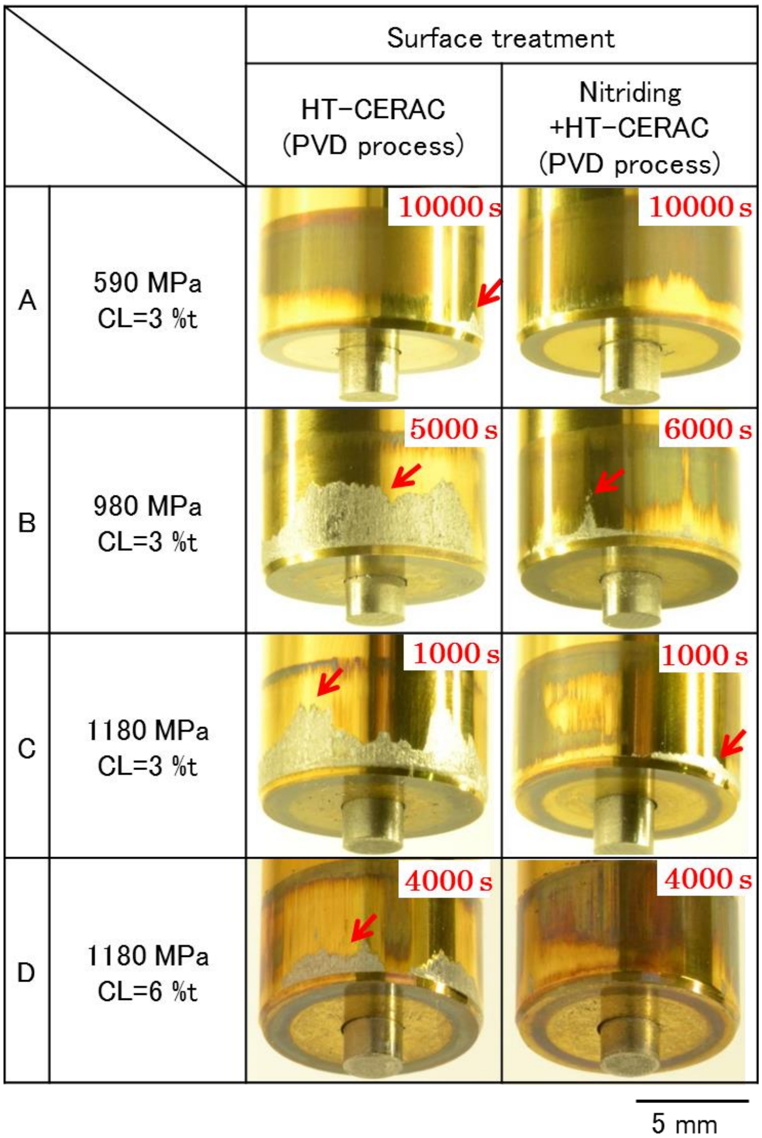

Fig. 13. Punch appearance comparison of nitriding+HT-CERAC.

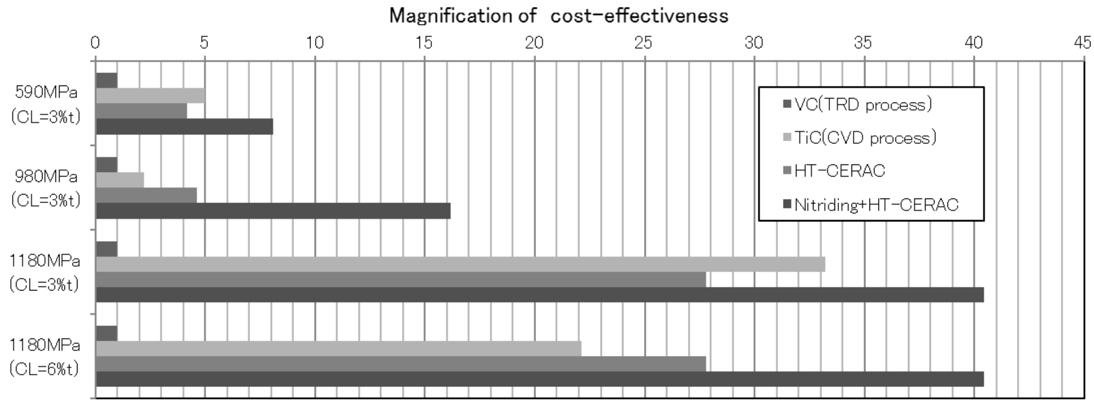

Fig. 14. Cost-effectiveness comparison of nitriding+HT-CERAC coated punch.
(Cost-effectiveness of VC coated punch = 1)

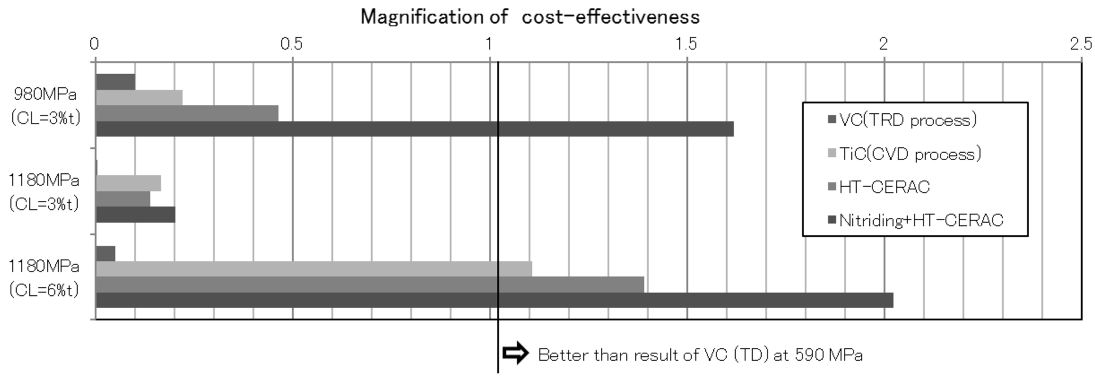

Fig. 15. Cost-effectiveness comparison of HT-CERAC coated punch.
(Cost-effectiveness of VC coated punch in 590 MPa high strength steel = 1)

4. Summary

Ceramic coating service life evaluation test which can evaluate galling mode failure by using the piercing process with progressive die were established.

Findings of this study are summarized as follows:

1. The service life was improved by 6 to 10 times by applying clearance change from 3%t to 6%t.
2. In case of this piercing test with high strength steel sheets, HT-CERAC along with PVD coating has equal to or better galling resistance compared to CVD and TRD coating.
3. Service lives of HT-CERAC punches were improved by 1.5 to 3 times by applying nitriding before coating. Therefore it is estimated that coating punches for 980 MPa and 1180 MPa class sheets piercing process can be produced with the same cost as TRD coated punches for 590 MPa class sheets by applying nitriding+HT-CERAC and adjusting clearances between dies and punches.

(Reference)

1) Kazumasa Yamazaki: Journal of the JSTP, 46 (2005), p565-.
2) Ryuji Sugiyama: Journal of the JSTP, 46 (2005), p552-.

3) Nikkei Automotive Technology, 11 (2012), p44-.
4) Junichiro, N.: Sokeizai, 51 (2010), No.8, p13-.
5) Masuda, T. and Kitagawa, T.: Technical papers of Conference on Die and Mold Technology, 2013, p.100.

