Research Article

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Microstructural Evolution and Deterioration of Cryogenically Treated S45C Steel After Pack Carburizing Process

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ABSTRACT

This paper presented the study of microstructure alternation and degradation of deep cryogenically treated S45C steel after pack carburizing. The microstructural observation showed that deep cryogenically treated S45C steel after pack carburizing contained a greater amount of martensite and a less amount of retained austenite than pack carburized S45C steel. Besides, globular cementite particles were also found in deep cryogenically treated S45C. Deep cryogenically treated S45C show the better degradation resistance in comparison to that of packed carburized S45C steel . Thus, the combined effect of pack carburizing and deep cryogenic treatment can promote the transformation of retained austenite into martensite and favor the distribution of globular cementite in the matrix of S45C steel, resulting in the significant improvement in the degradation resistance of deep cryogenically treated S45C steel.

Keywords: Pack carburizing, Cryogenic treatment, S45C steel

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Introduction

Due to rapidly growing technology in manufacturing process, the demand of the high-quality tool steels with high reliability is obvious [1-2]. In response to this demand, the high efficiency tool steels with the effective treatment processes have been produced [3]. Basically, the high-performance tool steels contain high content of significant elements, i.e., carbon, chromium, and vanadium. Besides, the cost of add-on treatments, such as cryogenic treatment, may be included [4]. Thus, using such high-quality tool steels would be costly for the manufacturing processes. As the manufacturing cost of the engineering component is always significant and it must be properly controlled [4-5]. The development of the tool steels offering the cheaper choice with almost the same manufacturing performance is therefore required.

S54C steel is a kind of the medium carbon steel with no addition of useful alloying elements for heat treatment [6]. Nowadays, it becomes extensively utilized in many industries and appropriate modification of this material would provide a cheaper alternative for modern industries [7].Technically, pack carburizing is a well-known technique which can increase the carbon content in the steel, promoting the formation of case hardening of the steel [8]. It is also known that deep cryogenic treatment is a supplemental process which is normally performed after the conventional heat treatment [9-10]. The advantages of this method are to increase amount of martensite and reduce the amount of retained austenite [11]. It also facilitates the formation of the precipitated carbides with the uniform distribution throughout the steel [12]. All can enhance the performance of steel, especially metal forming performance. Thus, it is of significant interest to perform the study on the microstructural evolution and monitor the manufacturability of cryogenically treated S45C steel after pack carburizing process. The results of this study would certainly support the heat treatment of steel, particularly tool steels.

In this present study, S45C steel initially experienced the pack carburizing followed by hardening and then tempering. Finally, it was submitted to the deep cryogenic treatment. Microstructure alternation and hardness profile were investigated. Besides, the reduction of shear band as the degradation of the treated S45C steel was monitored to understand the role of the pack carburizing and the deep cryogenic treatment applied on S45C steel.

Experimental procedure

The present investigation was conducted by using S45C tool steel. Table 1 shows the chemical compositions of S45C tool steel.

Table 1 Chemical compositions of the S45C tool steel used in this study.

Sample	C	Si	Mn	Cr	Mo	V	P	S
S45C	0.44	0.28	0.72	N/A	N/A	N/A	0.025	0.03

S45C steel punch samples of this experiment were prepared according to Figure 1. Dimension of punch samples was also given in this figure. Punch samples were divided into two groups. Punch samples in the first group were submitted to the pack carburizing followed by hardening and two tempering processes and samples of this group were labelled as “pack carburized S45C steel”. Punch samples in the second group were subjected to the pack carburizing followed by hardening, two tempering processes and finally the deep cryogenic treatment. The samples of the second group were designated as “cryogenically treated S45C steel”. Pack carburizing in this investigation was performed at 680 ^{0}C with the holding time of 30 minutes. In this step, samples were kept in the carburizing environment prepared by the mixture of the charcoal and tamarind catalysts. Samples were then quenched in oil medium and subsequently subjected to two tempering processes at 120 ^{0}C for 1.5 hours. Deep cryogenic treatment of S45C steel samples in the first group was carried out at -190 ^{0}C for 3 hours within the closed container prepared by the liquid nitrogen. The schematic diagram in Figure 2 showed the heat treatment conditions of cryogenically treated S45C steel samples in this experiment.

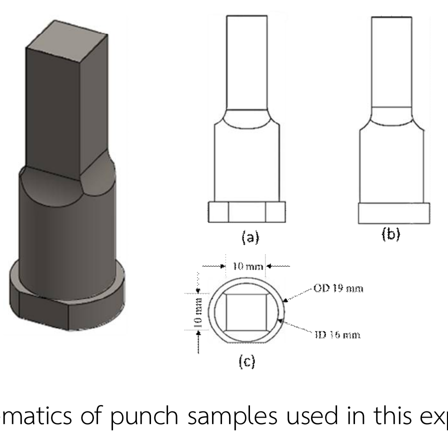

Figure 1 Schematics of punch samples used in this experiment:
(a) Front view (b) Side view and (c) Top view.

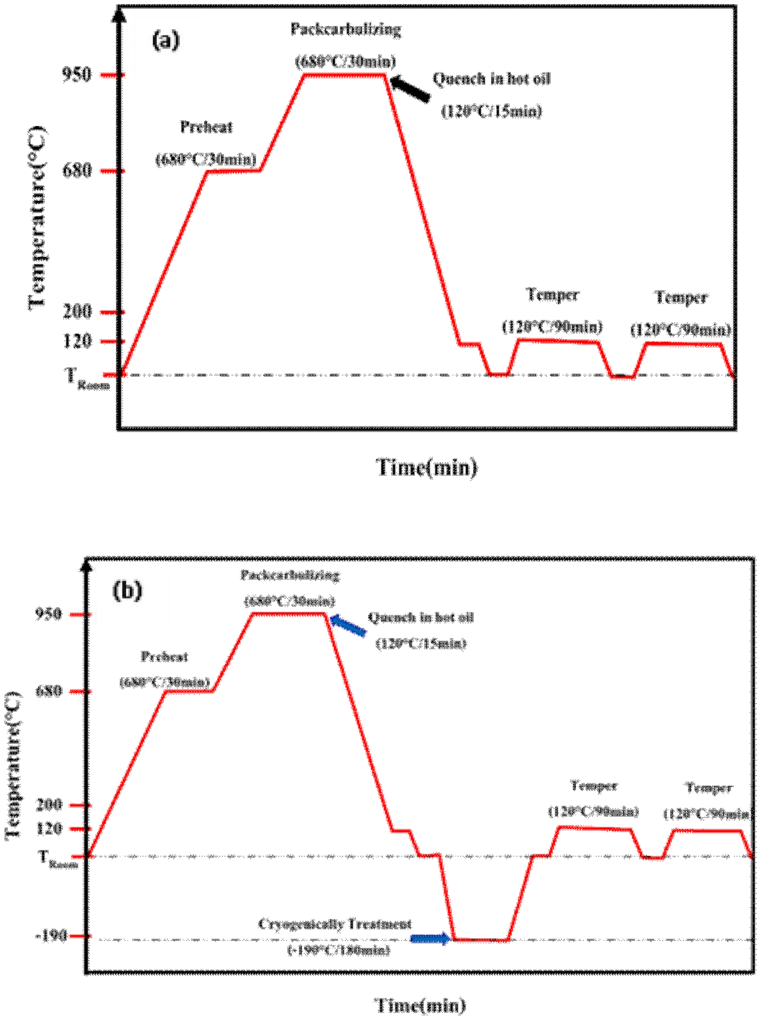

Figure 2 Schematics diagram showing the treatment conditions of S45C punch samples: pack carburized S45C steel and (b) cryogenically treated S45C steel.

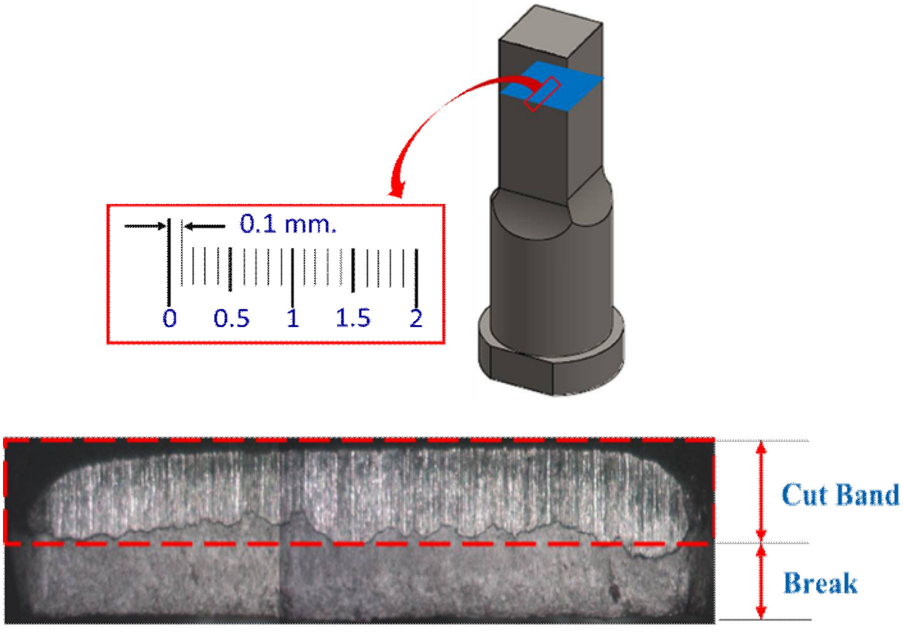

Figure 4 Locations of the cut band measurement degradation in on the samples.

Results

1. Microstructure and phase analysis

Figure 5 showed microstructure of pack carburized S45C steel punch. It is obvious from Figure 5(a) that the microstructure of pack carburized S45C steel at the edge of the samples mainly consisted of tempered martensite and retained austenite, but that at the middle of sample composed of fine pearlite and ferrite as seen from Figure 5(b). Figure 5(c) showed the results from SEM micrograph of the microstructure at the sample edge displayed the presence of martensite.

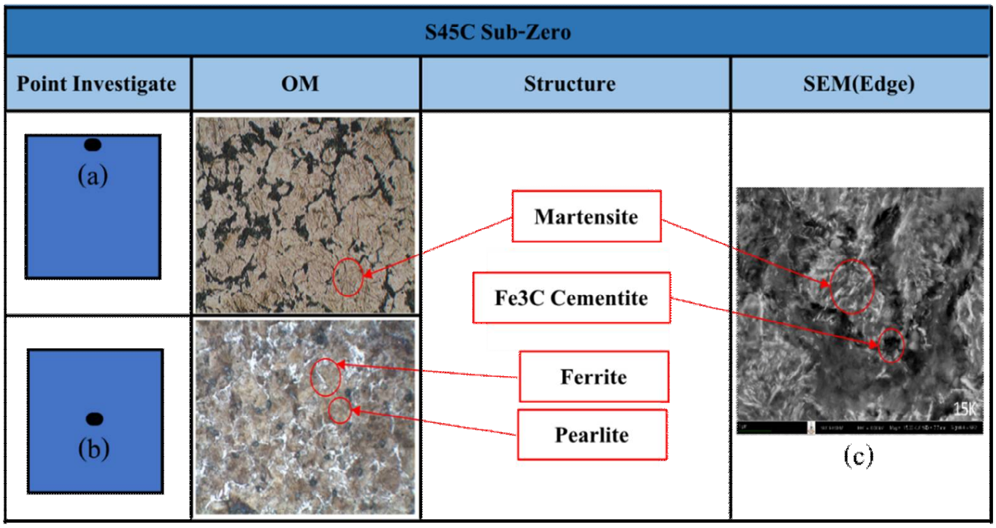

Figure 5 Microstructure of S45C steel subjected to pack carburizing and conventional heat treatment.

Figure 6 revealed the microstructure of cryogenically treated S45C after pack carburizing. It is evident from Figure 6(a) that a considerable amount of martensite was observed from the microstructure of the sample edge. However, irregular patches of retained austenite were also detected. Basically, pack carburizing can increase the carbon content of steel, particularly in the edge region. In addition, cryogenic treatment can facilitate the transformation of retained austenite into martensite. Thus, addition of two treatment processes attributes to the increased amount of martensite and the decreased amount of retained austenite.

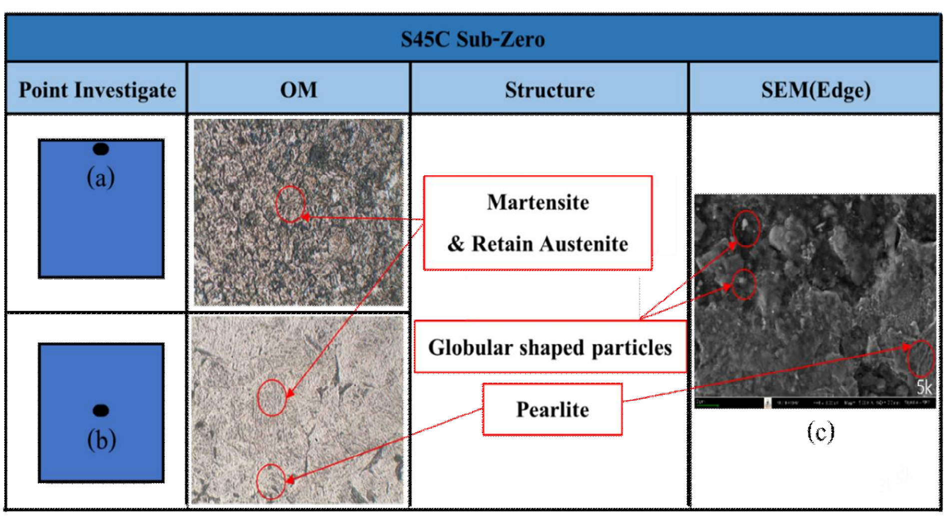

Figure 6 Microstructure of cryogenically treated S45C steel after pack carburizing.

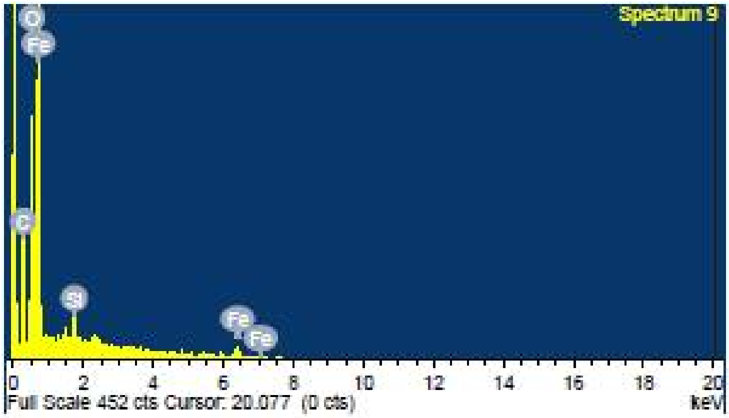

Figure 7 Element analysis using EDX at the sample edge.

The optical micrograph taken at the middle of the sample showed the mixture of martensite and fine pearlite structure and small portions of retained austenite, as seen from Figure 6(b). This finding highlighted the significance of the deep cryogenic treatment which can facilitate the transformation of retained austenite into martensite. The results from SEM as shown in Figure 6(c) indicted the appearance of globular shaped particles. To find more information of globular shaped particles, the element analysis using EDX was carried out at the sample edge and the analysis result was shown in Figure 7. It was found from Figure 7 that there was a significant appearance of iron and carbon. SEM micrograph with EDS analysis was then performed to obtain the more understanding in the globular shaped particles. Figure 8 shows the moderately uniform distribution of iron and carbon. Thus, the globular shaped particle would be globular cementite, precipitated throughout the structure of the sample edge. This also implies that the deep cryogenic treatment can assist the distribution of carbon, which subsequently became the globular cementite particle.

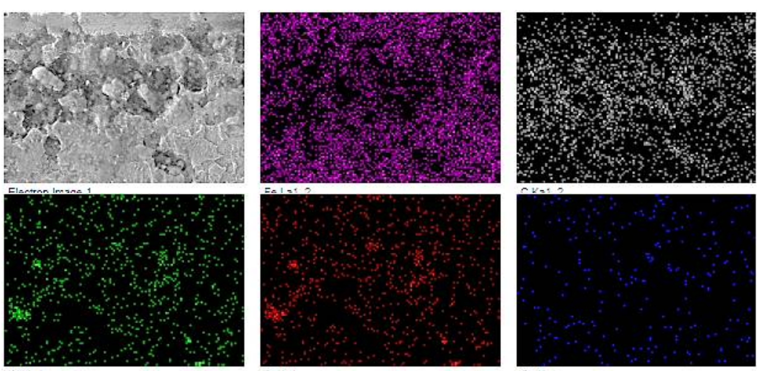

Figure 8 SEM micrograph together with EDS analysis at the cryogenically treated S45C sample edge.

2. Precipitation of carbide hardness measure

The hardness measurement carried out on the pack carburized S45C steel sample and the cryogenically treated S45C steel sample was displayed in Figure 9. The difference of the hardness profile of both samples indicated the difference in microstructure. In case of pack carburized S45C steel, the highest hardness was found at the edge of the sample and then the hardness significantly decreased. Usually, pack carburizing can increase the carbon content in the steel, particularly in the edge region of samples and distance of carbon diffusion depends on time and temperature set in the pack carburizing [11-12]. After hardened, the steel can contain different structures, depending on the distance from the edge [13]. Basically, the edge of hardened steel contains martensite. However, the amount of martensite decreases, but the amount of pearlite as well as ferrite increases with an increase in the distance from the edge [13-15]. Thus, the variation of the amount of martensite due to the pack carburization was responsible for the hardness variation of packed carburized S45C steel. For cryogenically treated S45C steel, its hardness profile did not show a significant decrease. This result confirmed that the deep cryogenic treatment enhanced the distribution of carbon, resulting in the formation of the larger portion of martensite in the cryogenically treated S45C steel. In addition, the distribution of carbon promoted the formation of uniform dispersion of globular shaped cementite particles in the cryogenically treated S45C.

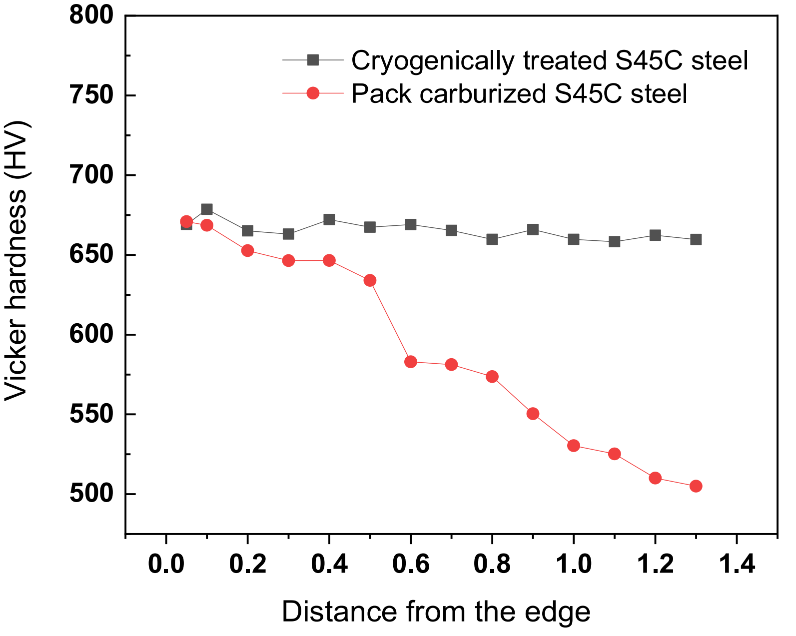

Figure 9 The hardness of pack carburized and cryogenically treated S45C steel punch sample.

To gain the statistics information of the measured hardness, we produced the statistics analysis from Figure 9 in Figure 10. From the statistics evidence shown in Figure 10, the hardness of the cryogenically treated S45C show a constant variation and from the fitting line, it was found that cryogenically treated S45C showed the maximum hardness reduction of 1.9 % at the distance from the edge of 1.3 mm. Considering the results of the pack carburized steel, we found that the hardness continuously decreased with an increase in the distance from the edge and the maximum hardness reduction of 24.9 % at the distance from the edge of 1.3 mm.

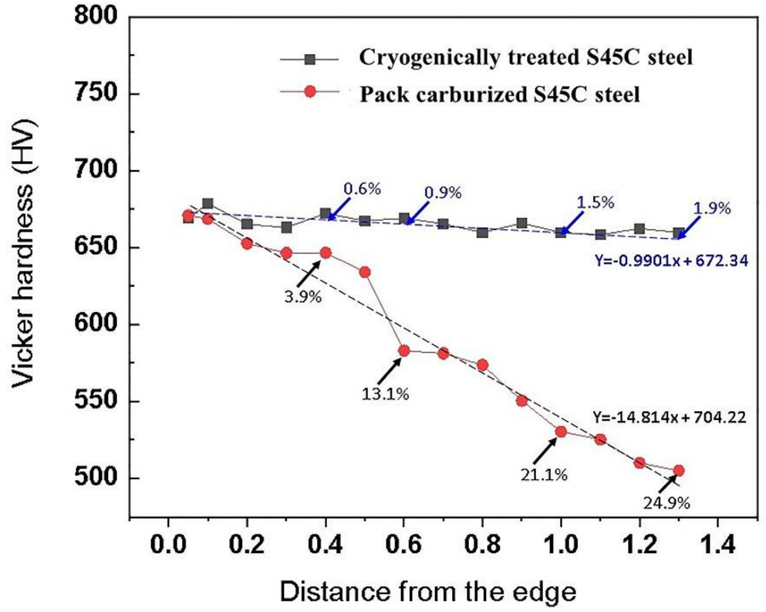

Figure 10 The statistics analysis of the measured hardness of Figure 9**.**

3. The degradation in S45C punch

Pack carburized and cryogenically treated punch samples were employed in the actual blanking process and the workpiece was a AISI 1020 steel plate.

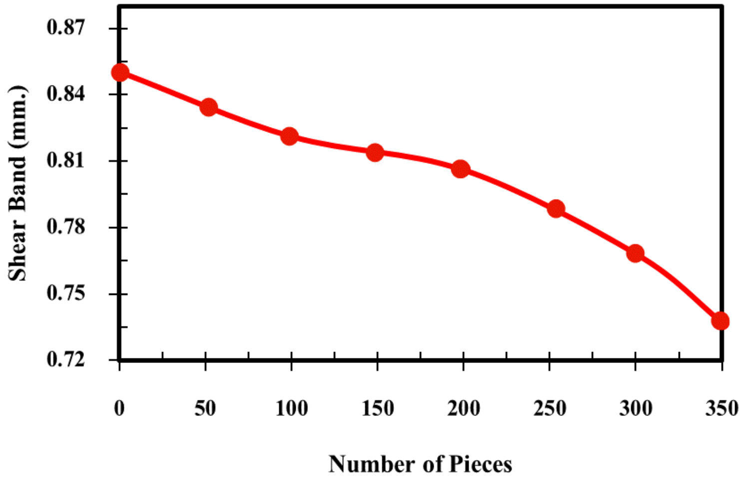

Figure 11 The variation of cut band of pack carburized S45C steel punch during the actual forming process.

Figure 11 shows the alternation of the shear band of the pack carburized S45C steel punch during the blanking process. It was obvious that the punch decreased greatly with an increase in the number of workpieces.

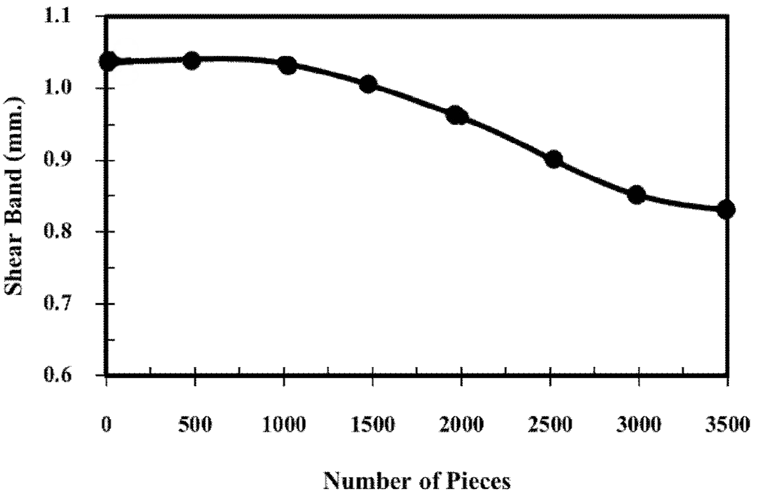

Figure 12 The variation of cut band of cryogenically treated S45C steel punch during the actual forming process.

Figure 12 exhibited the degeneration of the shear band of the deep cryogenically treated S45C steel punch during the blanking process. It was clear that this punch can produce the considerable higher number of workpieces with respect to the pack carburized S45C steel punch. The punch degradation was almost constant in the initial forming process and accelerated in the intermediate forming process to the end of the forming process. Obviously, the cryogenically treated S45C has more degradation resistance in comparison to the packed carburized S45C. This reflected the significance of the microstructure modified by the pack carburizing and the cryogenic treatment. As amount of martensite increased and globular cementite still dispersed in the martensite matrix, the resistance to metal-forming degradation increased, resulting in the improved degradation resistance of cryogenically treated S45C steel.

Conclusion

Microstructural modification and degradation observation of deep cryogenically treated S45C steel was systematically conducted. The results from microstructure observation indicated that the pack carburizing can increase the carbon content in the steel edge. The deep cryogenic treatment played a role in the transformation of retained austenite into martensite and facilitated the carbon distribution, resulting in the formation of globular cementite particles dispersed in the martensitic matrix of deep cryogenically treated S45C steel. Both add-on processes can improve the microstructure and enhance the hardness property. The degradation resistance of deep cryogenically treated S45C steel punch was obviously better than that of packed carburized S45C. Thus, combination of pack carburizing and deep cryogenic treatment can enhance the microstructure modification of S45C, resulting in the improved hardness and degradation resistance of S45C steel

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