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Precision piercing and blanking of ultrahigh-strength steel sheets

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Abstract

The paper proposes new technologies able to improve the surface quality of sheared products by means of a combined process of finish blanking and press shaving applied to materials having very high strength. Experimental researches were developed and the best combination of process conditions was identified. Furthermore, the technology was checked of so-called delayed fracture properties of the products by subjecting them into a solution of hydrochloric acid. They also have proved to possess good anti-delayed fracture properties.

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1. Introduction

In recent years, car chassis includes many parts made of ultrahigh-strength steel sheets such as 980 MPa grade sheets or steel sheets of even higher strength. To provide holes and blanks for these high strength steel sheets, conventional press blanking/piercing is widely used because of its high productivity and cost performance. However, for precise holes conventional press blanking/piercing shows poor quality with rough sheared surface, and generally needs further finishing operations such as lathing or grinding. Thus, many special working processes have been

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Masao Murakawa et al. / Procedia Engineering 81 (2014) 1114 – 1120

developed to improve the quality. Howard (1960) and King (1977) developed finish blanking and piercing process which enabled to obtain good edge finish of blanked or pierced components using conventional presses and the die-set installed on them. The process is characterized by a rounded die/punch tip in conjunction with a small clearance between punch and die. The press-shaving process is characterized by an initial step of conventional blanking/piercing and the second step of shaving or cutting wherein another set of shaving tool with a very small tool clearance is used to shave or cut the blanked/pierced surface with rough edge finish.

Our aim is to pursue the possibility of replacing the conventional manufacturing process, in which soft materials are first blanked/pierced and then hardened, followed, e.g., by a grinding step to realize the necessary dimensional/surface quality by the present simple (cold) press-working process of finish blanking/piercing of hardened materials followed by press shaving, thus increasing the productivity and reducing cost. In view of the possibility of delayed fracture to be caused for these pierced/blanked products, that was also checked with a result that this new press-working process has also a good delayed fracture resistant feature.

Nomenclature

| Symbol | Definition |
|--------|------------|
| \( t \) | thickness of work material |
| \( d_{P0} \) | diameter of blanking punch |
| \( d_{D0} \) | diameter of piercing die |
| \( d_{P1} \) | diameter of shaving punch |
| \( d_{D1} \) | diameter of shaving die |
| \( C_l \) | clearance between punch and die |
| \( C_{l0} \) | blanking/piercing clearance between punch and die |
| \( C_{l1} \) | shaving clearance between punch and die |
| \( \delta \) | shaving allowance |
| \( \delta(H) \) | shaving allowance for hole punching/cutting |
| \( \delta(B) \) | shaving allowance for blank punching/cutting |
| \( R_d \) | cutting tip radius of die |
| \( R_p \) | cutting tip radius of punch |
| \( T_s \) | tensile stress of work material |

2. Experiment

2.1. Experimental procedure

To investigate the surface quality and dimensional precision of a circle profiled product obtained by the finish piercing/blanking process followed by the press-shaving process, a 600 kN servo press was used, and the effects of processing speed, particularly those during the shaving step in which the quality could depend on the processing speed was verified. The press can provide a step-less speed range from 1 spm to 70 spm (2 mm/s to 140 mm/s on average). Fig. 1 shows finish piercing/blanking die set; (a) the outline of the die set and (b) specification of the die set used for piercing/blanking the starting material for shaving. This die-set is also used as the shaving die-set in which a different set of punch and die is installed into the die set. It is noted here that work material has two 10mm-diameter holes into which are inserted the two corresponding knock pins provided on the lower die set.

Preparation of materials to be shaved: the materials to be shaved were prepared with a tool set with the smallest possible tool clearance \( (C_l) \) so as to realize a cut surface comprised mostly of a very smooth edge finish without any fractured portion, thereby allowing the use of the smallest possible shaving allowance \( (\delta) \) in the following step to obtain a completely smooth, shaved cut surface. Accordingly, a tool set with a clearance of \( C_l=1.4\%t \) and \( R_p=0 \) mm and \( R_d=0 \) mm was used for fabricating the materials to be shaved in the case of SPFC980Y. In the case of SK85 (quenching & tempering), 0.5\%t clearance was used. Moreover, because SK85(q & t) had such a high hardness as to possibly lead to cutting edge chipping, the first-step blanking punch cutting edge tip was rounded to \( R_p=0.4 \) mm. In other words, the SK85 material, which was made of very hard material was prepared by means of so-called “hole finish blanking” instead of usually employed simple hole blanking, so as to increase the ratio of sheared surface to
fractured one to a high value as much as possible, because conventional blanking employing a sharp edge punch would not realize the said high ratio value which is necessary to the successful shaving step.

Table 1 shows the mechanical properties of the work material used for the experiment, and Table 2 shows typical element content of the work material.

![Diagram of the die set with labels: Punch, Blank holder, Work material, Die, Spring, R_d, R_p.](image)

(a) Outline of the die set

(b) Specification of the die set

Table 1. Mechanical properties of the work materials used in the experiment.

| Work materials(Thickness t) | Hardness (HV) | Tensile strength TS (MPa) | Elongation (%) |
|-----------------------------|--------------|--------------------------|---------------|
| SPFC980Y (t=1.4 mm)        | 304          | 1042                     | 14            |
| SK85 quenching & tempering (r=4 mm) I | 350    | 1070                     | 9.74          |
| SK85 quenching & tempering(r=4 mm) II | 400    | 1283                     | 8.71          |
| SK85 quenching & tempering(r=4 mm) III | 460    | 1487                     | 7.22          |

Table 2. Typical element content of the work materials used for the experiment.

| Work materials | C  | Si | Mn | P  | S  | V  | Nb | Cu | Ni | Cr |
|----------------|----|----|----|----|----|----|-----|----|----|----|
| SPFC980Y      | 0.17 | 1.32 | 2.2 | 0.009 | 0.001 | 0.009 | 0.004 | — | — | —   |
| SK85 (q & t)  | 0.8 | 0.2 | 0.4 | 0.008 | 0.004 | — | — | 0.007 | 0.0015 | 0.135 |

Choosing the appropriate shaving allowance (δ): Murakawa et al. (2013) have found that in the case of SPFC980Y blanked product generally had poor dimensional precision in terms of its outer diameter with 0.04 to 0.06 mm larger dimension than the die diameter. As is later explained, this is why the press shaving process is worthwhile although the process is an additional one.

Fig. 2 shows the shaving process schematically: the process consists of (a) punching the work material into a blank and a hole remainder, i.e., a hole for shaving plus two pilot holes; (b) locating the blank via a jig; (d) shaving the blank into a product and/or (c) shaving the hole remainder into a hole product utilizing the located pilot holes fitting with corresponding pilot pins. δ can be calculated using the experimentally established equation of δ(Hole)=diameter of shaving punch (dP1)-diameter of punch for making the material to be shaved (dP0)/2 and δ (Blank) ≈diameter of die for making the material to be shaved (dD0)-diameter of shaving die (dD1)/2. Thus SPFC980Y material was subjected to (a) the first conventional step of blanking/piercing process and (b) the second step shaving process without resorting to finish piercing/blanking in the aforementioned (a) step.
2.2. Results on the cut surfaces obtained by a combined finish blanking/piercing and press shaving process

Referring to the conventional shaving experiment of SPFC980Y material, Fig. 3 shows blank and hole cutting surfaces before and after shaving with tool parameters shown in Table 3. As shown in Fig. 3, the blank is almost perfectly shaved into a smooth cut surface after shaving, while the as-pierced hole with rough edge finish is converted into an about 90% smoothly cut hole surface. Then what will be like with regards to dimensional accuracy of the shaved product. Although not shown, the poor as-blanked diameter accuracy has been effectively improved approaching near the shaving die inner diameter and the hole diameter accuracy has been also improved approaching near the diameter of shaving punch respectively with increase in the shaving speed $V$.

Table 3. Tool parameters for conducting the shaving process in Fig. 2.

| Processes         | Tool diameter   | Object of shaving process | Tool tip radius |
|-------------------|-----------------|---------------------------|-----------------|
|                   | Punch outer diameter $dP_0$ (mm) | Hole                     | $R_p=0$ mm     |
| Blanking process  | Die inner diameter $dD_0$ (mm)   | Blank                    | $R_d=0$ mm     |
|                   | Punch outer diameter $dP_1$ (mm) | Hole                     |                |
|                   | Die inner diameter $dD_1$ (mm)   | Blank                    |                |
| Shaving process   | Shaving allowance $\delta(h)$ or $\delta(b)(mm)$ | 0.13                     |
|                   | $dD_1$ (mm)      |                           | 0.125           |

As for the shear droop about 20 % reduction was found in the case of blank product, while only insignificant improvement was found in the case of pierced hole product which seems to cause an inherently small droop formation because of the less flow-in of the material around the hole.

Fig. 4 shows the relationship between the hardness of the starting material to be shaved (from 350 Hv to 460 Hv) and the surface quality (Murakawa et al.,2012) in which the die set shown in Fig. 1(a) and tool conditions shown in Table 4 were used. Tool conditions shown in Table 4 enabled the first step of finish hole blanking (resulting in relatively good edge finish because of the rounded punch tool tip effect), and the second step of shaving with sharp edge tools (resulting in completely good edge finish because of tool tip cutting effect). Thus, all the resulting surfaces of the material after shaving are completely smooth. However, it is noted here that there is a very unusual pierced surface to be shaved in the case of 460 HV material; that surface consisted of (1) a very narrow sheared surface, (2) a very narrow primary fractured surface, (3) a relatively wide secondary sheared surface, and (4) a relatively narrow secondary fractured surface. According to Murakawa et al. (2013), it seems most likely that the fracture at location (2) is a bumpy conventional secondary fracture portion, and is not something of a scab nature comprising a component different from the material itself. Although the detail is shown by Murakawa et al. (2012) and Shionome et al. (2013), even in the case of a very thick ($t=4$ mm) and hard (HV=460; 45HRC Grade; equivalent TS 1500 MPa Grade) SK85(q & t) material or even harder (55 HRC Grade; TS 2075 MPa Grade) SK85(q & t) material, the effectiveness of the present combined finish piercing(hole blanking) and press shaving.
process improved not only surface roughness up to about $R_z$ of 4.00 $\mu$m on average, but also dimensional accuracy since a difference value between the blanking punch diameter and the pierced material hole diameter was clearly reduced to a difference value between the shaving punch diameter and the shaved material hole diameter.

Table 4. Conditions for making the material to be shaved ($t=4.0$ mm) and the shaving process tool.

| Condition for making the material to be shaved | Condition for shaving, $e(0)=0.02$ mm |
|-----------------------------------------------|---------------------------------------|
| $C_l=0.5 \%$ | $C_l=1.25 \%$ |
| $dP_0=\phi 19.56$ mm ($R_p=0.4$ mm) | $dP_1=\phi 19.40$ mm ($R_p=0.0$ mm) |
| $dD_0=\phi 19.40$ mm ($R_d=0.0$ mm) | $dD_1=\phi 19.50$ mm ($R_d=0.0$ mm) |

2.3. Results on checking of the delayed fracture properties of SK85(q & t) material

Delayed fracture is believed to be a kind of stress induced hydrogen embrittlement phenomenon, and Mori et al. (2013) investigated the punchability of ultra-high strength steel sheets using punch with small round edge, and found that the delayed fracture can be prevented due to large compressive stress around the sheared edge. Since steel sheets having a hardness more than 400 Hv (equivalent to about 40 HRC) can cause delayed fracture, we investigated whether these sheared and shaved hole products can cause cracks due to delayed fracture. As a means of checking delayed fracture an immersion test of steel sheets in the diluted hydrochloric acid solution has been proposed by Hikida et al. (2013), in which the test samples were immersed into pH 1 hydrochloric acid solution at 30 degrees C for 100 hours to check the cracks. Referring to the test of circular shaved holes or linear cut samples, the circular hole samples prepared from 55, 45 and 35 HRC SK85(q & t) material (Shionome et al., 2013) were cut orthogonal to the longitudinal direction of the samples using a grinding cutter machine, and linear shaped specimens were prepared by a linear shear cut device used by Komuro et al. (2013). They were respectively subjected to the immersion test after measuring their residual stress using an XRD device. Other machined samples were also used as reference test samples. As is clearly shown in Table 5 and Fig. 5, the present method of combined finish hole
Table 5: Results of immersion test in dilute hydrochloric acid solution of sheared samples etc.

- denotes no occurrence of delayed fracture cracks, X: denotes occurrence of delayed fracture cracks

| Hole cut or Linear cut | Thickness/t (mm) | Processing mode | Hardness (HRC) | Occurrence of cracks | Residual stress (MPa) | Sample No. |
|-----------------------|------------------|-----------------|----------------|----------------------|-----------------------|------------|
| Hole cut 2            | 2                | As pierced      | 55             | X                    | 824 (Tensile)         | ①         |
| Hole cut 2            | 2                | 2 shaving steps | 55             | @                    | -502 (Compressive)    | ②         |
| Hole cut 3            | 2                | 2 shaving steps | 55             | @                    | -349 (Compressive)    | ③         |
| Hole cut 4            | 2                | 2 shaving steps | 55             | @                    | 7.5 (Tensile)          | ④         |
| Linear cut 2          | 2                | Cut by fine cutter | 55          | @                    | Unmeasured            | —          |
| Linear cut 6          | 2                | Buffing after wire cutting | 55     | @                    | 41 (Tensile)          | ⑥         |
| Linear cut 6          | 3                | Grinding of ⑥   | 55             | @                    | -513 (Compressive)    | ⑦         |
| Linear cut 6          | 3                | 3 shaving steps after sheared at 17 mm offcut length | 55     | @                    | -727 (Compressive)    | ⑧         |
| Linear cut 6          |                  | As sheared at 3 mm offcut length | 55   | X                    | 364 (Tensile)         | ⑨         |
| Linear cut 6          |                  | As sheared at 3 mm offcut length | 35   | @                    | -153 (Compressive)    | ⑩         |
| Linear cut 6          |                  | As sheared at 3 mm offcut length | 45   | @                    | 130 (Tensile)         | ⑪         |

Hole piercing and shaving can effectively prevent the delayed fracture.

3. Conclusions

We have looked into a new process able to yield good edge finish and dimensional precision without loss of good productivity by a method of combining finish hole blanking (finish piercing) and press shaving for the already quenched, tempered and very hard SK85 material to innovate the conventional manufacturing process for making very precise hole products having very high hardness. More specifically, the process for manufacturing circular components with high hardness and precise inner diameter conventionally comprises the first manufacturing step of blanking soft starting SK85 material followed by the second step of quenching and tempering and then the final third step of grinding/turning for realizing the precision. The present process is very innovative in that it can yield hole products with very high precision of inner diameter as well as good inner surface quality without sacrificing process productivity because the process requires neither quenching and tempering after punching nor subsequent time-consuming grinding/turning operation. Thus, time and cost reductions should be substantial. The key point in making this method successful is to find the best parameters condition of tool in the first-step finish piercing and the second/third-step shaving. We have succeeded in obtaining hole products with good dimensional accuracy and good edge surface quality for thick (up to 4 mm) and hard (up to 55 HRC; equivalent TS 2075 MPa grade) SK85 (Q & T) material. The possible occurrence of delayed fracture often concerned was also checked; this combined process has proved to possess good delayed fracture resistant properties as well. Future work, from the viewpoint of mass production, may include the best tool material selection.
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