MEET THE JOB SPECIFICATION FROM THE CUSTOMER

the evaluation of a high wear resisting tool steel for a progressive die for the production of components of safety belts

A. Wong
Ngai Cheong Metal Industries Sdn Bhd
Lot 41730 Bt 14, Jalan Puchong,
47100 Puchong, Selangor, Malaysia

P.K. Thay
Bohlasia Steels Sdn Bhd
No. 9 Jalan SU 25, Taman Industri Selayang Utama,
68100, Selayang, Selangor, Malaysia

W. Furtner
Böhlter International GmbH
Nordwestbahnstraße 12-14,
A-1201 Wien, Austria

H. Makovec, H. Eder, F. Russ
Böhlter Edelstahl GmbH
Mariazeller Straße 25, P.O. Box 96,
A-8605 Kapfenberg, Austria
Abstract

For the production of components for safety belts in compliance with QS 9000 and SPC control up to CPK >1.33, proper tool design and materials are demanded. To fulfil the stamping requirement like no burr, no tear, 100% sharp edge on the locking tooth the progressive die construction (length 1500 mm) especially the position of the main and sub guides is important.

The output of 45 pieces per minute (two components will be produced at the same time by using waste area of the strip) needs high performance presses and tools. The monitoring of the process FMEA, the evaluation of cutting edge geometric condition including frequency of grinding and service leads to a tabulation of production records, SPC control data and CPK value. The paper discusses tool design, influence of processes, tool material selection, especially the results with BOHLER K190 MICROCLEAN and introduces the next generation of frame die.

Keywords: Progressive die, tooling, die design, wear resistance, toughness, compressive strength, stamping, press machines, knuckle link motion, crank link motion geometric

INTRODUCTION

Increasing demand on quality and consistency placed on the production of frame components for automotive safety belts (Fig. 1, R27 frame) has led to special focus on compliance with QS9000 and SPC control up to CPK > 1.33.

This translates, in production terms, into extremely stringent stamping operation that produces frame products with no burrs, no tear, and 100% sharp edge finish on the locking teeth at the gear area of the frame.

The progressive tooling for the production of this frame component has to achieve an output of 45 pieces of frames per minute with two parts being produced at the same time, one using the waste area of the metal strip.

Furthermore, the following criteria have also be taken into consideration during die design and construction:

1 high production quantity on HARD raw material, QSTE 550;

2 fine cut edge finish on the stamped components;

3 to achieve good consistency on the significant characteristic (SC) and critical characteristic (CC) as specified by the customer;

4 to maintain a competitive price on the components produced to support the customer on their global purchasing program.
The construction of the progressive toothing with a length of over 1,500 mm which has to ensure the above targets are achieved would require careful selection of tool materials, tool accessories, and the choice of an appropriate press machine for the stamping and forming operations.

**DIE DESIGN AND CONSTRUCTION**

In order to ensure high and consistent quality on the frame components produced on a mass production basis, the design of the toothing is based on the major criteria described in the following paragraphs.

**DIE CONSTRUCTION**

The type of die construction for the components of this seat belt product is basically "progressive" in nature, Fig. 2, except for the last process of assembling the tie bars to the frame which requires a single process crimping tool. Due to the frame and reinforce plate, the progressive tool has a die length of 1.6 m and 0.8 m. Modular systems were used to ease the handling of process control and for easy model change and maintenance.

**SPRING FORCE**

The frame design demands fine cut finish on the edges, high clamping force has thus become a major consideration to bring about high enough force to prevent the movement of the sheet metal during cutting.
Low clamping force will result in the movement of the sheet metal during cutting operation, and this would lead to:

1. tearing of sheet metal on the cutting edges instead of a control shear finish;
2. shorter tool life caused by higher friction of sheet metal on the cutting edges;

The bending of the frame into U-shape was done with a roller bending-up friction-free process, which requires a high clamping force, otherwise, a good flatness and perpendicularity on the base of the bending area, and thus the concentricity of the holes between the two sides would not be achieved.

The stamping operation needs to perform a fine cutting edge finish on the entire gear area frame (Fig. 3). However, the type of press use in this case is not a fine blanking press (long bolster area need to be used on the progressive die). The fine cutting edge finish was achieved via a multiple shaving process with 2% shear clearance, with guiding elements of 14 µm pairing classification. The clamping force used in this operation was 40% (with $N_2$ gas spring force of about 100 tonnes) that of the cutting force.
STEEL SELECTION

The selection of steels is based on the process requirements at the specific areas of the die. Basically, the selection is based on three main criteria of die construction, there are:

- wear resistance
- toughness
- compressive strength

The edge holding and wear resistant properties are required in the cutting and forming actions of the die.

BÖHLER K190 was chosen for the many cutting operations because it exhibits very high wear resistance due to the presence of about 28% carbide particles, with substantial amount of vanadium carbide particles, in the as hardened condition (see Fig. 5).

Unlike conventional high carbon, high chromium steels, the large amount of carbide particles in BÖHLER K190 are very fine and uniformly distributed, thus, ensuring its high toughness [3], see Fig. 7 and Fig. 8.

Toughness are required in similar operations, especially so in the cutting of the sharp teeth of the frame (Fig. 6). Compressive strength is a very important factor in this operation; firstly, the sheet metal used in the production of
the frame has relatively higher tensile strength (QSTE 550). Secondly, the cutting clearance are very small, 0.035 mm per side, on a thickness of 1.7 mm.

Thus, high compressive strength is demanded on the steel used to make the die to ensure that the tool does not fail prematurely as a result mechanical deformation and excessive wear [4].
BÖHLER K340 was chosen for its high adhesive wear resistance and its excellent suitability to PVD coating.

Figure 6. Punch and die for cutting the sharp teeth of the frame.

BÖHLER K190 exhibits high level of toughness [1].

BÖHLER K340 was used mainly in the forming and bending operations where the area of contact between the tool and the sheet metal was large. This
contact tends to give rise to adhesive wear. The adhesive wear resistance of BÖHLER K340 is relatively higher than conventional 12% chromium steel [5] as shown in Fig. 9. The high adhesive wear resistance of BÖHLER K340 is achieved by the special alloying of aluminium and niobium.

The adhesive wear resistance of K340 in this particular operation is further enhanced by PVD coating. K340 responds exceptionally well to PVD coating; this may be attributed to the presence of aluminium in its matrix and also its hardness retention property at high temperatures.

Table 1. Summary of tool steels used in the construction of the progressive die

<table>
<thead>
<tr>
<th>Steel</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>BÖHLER K190 MICROCLEAN</td>
<td>2.30</td>
<td>0.40</td>
<td>0.40</td>
<td>12.50</td>
<td>1.10</td>
<td>4.00</td>
<td>—</td>
</tr>
<tr>
<td>BÖHLER K340 ISODUR</td>
<td>1.10</td>
<td>0.90</td>
<td>0.40</td>
<td>8.30</td>
<td>2.10</td>
<td>0.50</td>
<td>+Al, +Nb</td>
</tr>
<tr>
<td>BÖHLER K110</td>
<td>1.55</td>
<td>0.25</td>
<td>0.35</td>
<td>11.80</td>
<td>0.80</td>
<td>0.95</td>
<td>—</td>
</tr>
</tbody>
</table>

Figure 8. The compressive strength of BÖHLER K190 is comparable to that of high speed steels [4].
PROGRESSIVE DIE SAFETY FEATURE

The demand on the production of a large quantity of products on a single tool, and the need to share special and expensive press machine with other products, scheduling of production becomes very important to avoid unnecessary downtime. Also, tool and press machine failure due to accident must be avoided. Thus, safety features in the progressive die assembly has an important roll in minimizing the down time caused by mishandling during busy production schedules.

1 A misfeed pilot with a photo sensor is used to monitor the feeding during the progressive run.

2 At the end of the progressive die where the finished parts are ejected, a mis-eject sensor is installed.

3 At certain critical areas along the progressive die, stroke-end limit sensors with sensitivity between 2 and 50 µm are installed to monitor the average gap of the die close position. Any deviation from the setting caused by the presence of shearing chips or scraps, or other foreign objects will trigger the sensors and stop the press.

4 A load cell is also installed in the press to monitor all the forces used at the various stages of the operation. This not only allows force analysis

Figure 9. Adhesive wear resistance of BÖHLER K340 [4].
to be done on every stage during the try out adjustment and calibration, but also safeguard the tooling from unexpected and excessive load during the progressive operation.

SELECTION OF PRESS MACHINE

In the selection of the right press machine for the stamping of the seat-belt frame, the criteria as summarised in Table 2 were considered.

Table 2. Summary of features of the press machine

<table>
<thead>
<tr>
<th>Press Characteristics</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press Force</td>
<td>The frame product requires a 300-tonne press</td>
</tr>
<tr>
<td>Press Bolster</td>
<td>Minimum 2-meter bolster in this case</td>
</tr>
<tr>
<td>Slide Stroke</td>
<td>Slide stroke is related to the finish product height after drawing, forming or bending. A simple rule of thumb is the minimum slide opening height has to be at least 2 X’s product height. (A slide opening height of 100 mm was used in this case.)</td>
</tr>
<tr>
<td>Stroke per minute</td>
<td>The rate of the frame production is 45 strokes per minute</td>
</tr>
<tr>
<td>Press Frame</td>
<td>H-Frame press was used</td>
</tr>
</tbody>
</table>

OPERATIONS AND RESULTS

The try-outs and sampling of the R27 frame production went smoothly; however, during the production run, unexpected and frequent tool breakage and excessive tool wear were encountered, Fig. 10.

QUALITY OF HEAT TREATMENT AND STEELS

An investigation was launched to look into this problem starting with the feeding of the coil, tool setup and operation, the quality of heat treatment and tool materials, and also the press machine.

The feeding of the coil into the progressive tool was due to the initial inexperience in the handling of high tensile coil and it was overcome with practice.

Metallurgical investigation was carried out to determine if heat treatment and/or tool material might have been the problem. Observation of the microstructures revealed that the structures were that of a proper heat treated
structure with no obvious sign of grain growth, precipitation of carbide to the grain boundary, or decarburisation. The microstructures of the tool materials also showed that both the K190 and K340 exhibit cleanliness levels within their respective standards, and likewise their carbide distribution showed no segregation, as to be expected with a powder metallurgy (K190) steel and an electroslag remelted (K340) steel.

Figure 10. Frequent downtime as a result of chipping of tool inserts.

THE PRESS MACHINES

Having examined the various probable causes of unsatisfactory tool performance, attention was focused on the choice of press machine.

The first press machine (Press A) used in the production of the frames was a crank motion 300-tonne press.

Subsequently, a different design 300-tonne press machine (Press B) was used for this job. The results are shown in Fig. 11.

DISCUSSION

The change of focus of investigation on the premature tool failure from tool materials, heat treatment and die construction to press machine was a major and significant shift as it might involve the change of press machine.

Press A is an 'H' Frame crank motion press with a long bolster bed. Its selection was based on the assurance given by the press machine maker that
it was capable of carrying out the specified job. The shorter delivery time of the machine also played a very crucial role in choosing this machine.

Figure 11 shows the tool maintenance frequency as a result of tool failure initially on Press A (crank motion) and subsequently on Press B (knuckle link).

![Figure 11. Intervals of tool service and maintenance as a result tool insert failure.](image)

With **Press A**, in the process of achieving about 180,000 pieces of seat belt frames, the progressive die experienced a total of 10 tool breakdowns that required service and tool replacement. This gives an average figure of about 18,000 pieces per service.

The breakdown of the tooling mainly occurred at the teeth of the gear cutting inserts where extreme stresses were to be expected.

The progressive tool was transferred to **Press B** around the beginning of April 2001. Records showed that the next 220,000 pieces of frames produced using Press B only encountered 6 tool breakdowns; giving an average of
about 36,000 pieces per service. The progressive die is currently running at 45 strokes per minute. This change is very significant as the frequency of service was halved as a result of changing the press, not the tooling.

Press A has a long bolster bed, and it was suspected that the deflection of the bolster bed during close die position might have been an important factor in influencing the performance of the tool.

A measurement was taken and it was found that the deflection at the centre was 0.900 mm (Fig. 12). This deflection obviously would be transferred to the die that the bolster bed supposed to support.

**Figure 12.** Schematics of bolster deflection of crank and knuckle link motion presses.

Press B is specifically designed and developed for parts that require fine cutting edge finish and cold forging process. It incorporates a knuckle and link motion that allows it a 30s holding time (Fig. 13) before and after the bottom dead centre (BDC). Figure 14 shows a knuckle link motion press in operation.

The bolster design of Press B was much stronger. It was a single-piece casting, and the deflection of the bolster bed under a maximum load of 300 tonnes in a close die position was only 0.030 mm (Fig. 12) at the centre.
CONCLUSION
The case study above points to the fact that despite the use of best possible tool materials with special attention on tool design, the tooling may still
perform well below expectation if the quality of the press machine is not satisfactory.

In the construction of the progressive die, both electroslag remelted (ESR) and powder metallurgical quality steel grades were used at the most critical and severely stressed areas to ensure minimum unscheduled downtime due to tool material failure.

To achieve greater production efficiency, it can be concluded that three basic elements: die design, material selection, and press machines must work harmoniously and compliment each other (Fig. 15).

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REFERENCES

