There are cases where trouble, such as punch tip breakage and flange fractures, occurs during the punching operation. Often the cause of this trouble is a lack of technical data concerning standard parts, or an error in the selection of the punching tool material or shape. In order to reduce the incidence of this kind of trouble, standards for correct punch use, with consideration for factors such as the fatigue strength of tool steel and concentration of stress at flanges, are presented here.

### 1. Calculation of punching force

- **Punching force \( P \) [kgf]**
  \[
  P = \frac{Et}{\xi} \quad \ldots (1)
  \]
  \( E \): Pinching profile length [mm]
  \( t \): Thickness of workpiece [mm]
  \( \xi \): Workpiece shearing resistance [kgf/mm²]

- **Material thickness \( t \) [mm]**
  - 1: Material thickness
  - 2: Shearing resistance [kgf/mm²]

- **Material thickness \( t \) [mm]**
  - 1: Material thickness
  - 2: Shearing resistance [kgf/mm²]

\( \xi = 0.8 \times 10^{-6} t \) (for 1.2 mm thick)
\( \xi = 0.8 \times 10^{-5} t \) (for 2.8 mm thick)
\( \xi = 0.8 \times 10^{-4} t \) (for 6.4 mm thick)

\( \xi = 0.8 \times 10^{-3} t \) (for 12.8 mm thick)

### 2. Fracture of punch tip

- **Stress applied to punch tip \( \sigma \) [kgf/mm²]**
  \[
  \sigma = \frac{P}{\pi d} \quad \ldots (2)
  \]
  - \( P \): Punching force
  - \( d \): Diameter of punching tool

- **For the punch of the diameter \( d \) [mm]**
  \[
  \sigma = 4 \times 1.2 \times 64^{2.8} = 110 \text{ kg/mm}^2
  \]
  \[
  \sigma = 4 \times 2.8^{2} \times 64^{2.8} = 117 \text{ kg/mm}^2
  \]

### 3. Minimum punching diameter

- **Minimum punching diameter \( d \)**
  \[
  d = \frac{4}{\pi} \sqrt{\frac{P}{\sigma}} \quad \ldots (4)
  \]
  - \( P \): Punching force
  - \( \sigma \): Shearing resistance
  - \( d \): Diameter of punching tool

### 4. Fracture due to buckling

- **Buckling load \( P \) [kgf]**
  \[
  P = 0.8 \times 10^{4} \sqrt{d} \quad \ldots (5)
  \]
  - \( d \): Diameter of punching tool

- **Fatigue strength for tool steel [kgf/mm²]**
  - SKD11: 21000
  - SKH51: 22000
  - HAP40: 23000
  - V30: 6000

As indicated by Euler’s formula, steps which can be take to improve buckling strength include the use of a stripper guide, the use of a material with a larger Young’s modulus (SKD + SKH + HAP), and reducing the punch tip length. The buckling load \( P \) indicates the load at the time when a punch buckles and fractures. When selecting a punch, it is therefore necessary to consider a safety factor of 3–5.

When selecting a punch for punching small holes, special attention must be paid to the buckling load and to the stress which is applied to the punch.

### Example 1

Find the possibility of punch tip fracture when should punch \( SA60-50-P2.8 \) and Jector punch \( SA60-50-P2.8 \) (\( d \): diameter, 0.1 mm as shown on P. 186 are used. (Punching conditions are the same as in Example 1.)

- **For the shoulder punch, from Formula 2:**
  \[
  \sigma = 4 \times 1.2 \times 64^{2.8} = 110 \text{ kg/mm}^2
  \]
  \[
  \sigma = 4 \times 2.8^{2} \times 64^{2.8} = 117 \text{ kg/mm}^2
  \]

- **For the jector punch, from Formula 3:**
  \[
  \sigma = 4 \times 2.8^{2} \times 1.2 \times 64^{2.8} = 117 \text{ kg/mm}^2
  \]

From Fig. 2, we see that when \( \sigma = 110 \text{ kgf/mm}^2 \), there is the possibility of fracture occurring with an SKD11 punch at approximately 9,000 shots. When the material is changed to SKH51, this increases to approximately 40,000 shots. The possibility for the jector punch is found in the same way. Because the cross-sectional area is smaller, the jector punch tip fracture will occur at approximately 5,000 shots. Fracture will not occur if the stress applied to the punch during use is less than the maximum allowable stress for that punch material. (Consider this to be only a guide however, because the actual value depends on various factors in the die accuracy, die structure, and punched material, as well as the surface roughness, heat treatment, and other conditions of the punch.)
There are cases where trouble, such as punch tip breakage and flange fractures, occurs during the punching operation. Often the cause of this trouble is a lack of technical data concerning standard parts, or an error in the selection of the punching tool material or shape. In order to reduce the incidence of this kind of trouble, standards for correct punch use, with consideration for factors such as the fatigue strength of tool steel and concentration of stress at flanges, are presented here.

### 1. Calculation of punching force

- **Punching force** \( P \) [kgf]

\[
P = \frac{F}{t} r \quad \ldots (1)
\]

- **E**: Pinching profile length [mm]
- **t**: Material thickness [mm]
- **\( \rho \)**: Material shearing resistance [kg/mm²]

### 2. Fracture of punch tip

- **Stress applied to punch tip** \( \sigma \) [kgf/mm²]

\[
\sigma = \frac{P}{A} \quad \ldots (2)
\]

- **P**: Punching force
- **A**: Cross-section area of punch tip

### 3. Minimum punching diameter

- **Minimum punching diameter**: \( d_{min} \)

\[
d_{min} = \frac{4t}{\rho} \quad \ldots (4)
\]

### 4. Fracture due to buckling

- **Buckling load** \( P \) [kgf]

\[
P = \frac{E\sigma^2}{\sqrt{\pi^2/4 + 1}} \quad \ldots (5)
\]

- **\( E \)**: Young’s modulus [kgf/mm²]
- **\( \sigma \)**: Fatigue strength of tool steel [kgf/mm²]

### Table 1

<table>
<thead>
<tr>
<th>Material</th>
<th>Shear strength ( \sigma ) [kgf/mm²]</th>
<th>Tensile strength ( \sigma_t ) [kgf/mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>2~9</td>
<td>2.5~6.4</td>
</tr>
<tr>
<td>Tin</td>
<td>3~8</td>
<td>4~5</td>
</tr>
<tr>
<td>Aluminum</td>
<td>7~11</td>
<td>13~16</td>
</tr>
<tr>
<td>Duralumin</td>
<td>22</td>
<td>38</td>
</tr>
<tr>
<td>Copper</td>
<td>18~22</td>
<td>25~30</td>
</tr>
<tr>
<td>Brass</td>
<td>22~30</td>
<td>35~40</td>
</tr>
<tr>
<td>Bronze</td>
<td>32~40</td>
<td>40~50</td>
</tr>
<tr>
<td>Nickel silver</td>
<td>28~36</td>
<td>45~56</td>
</tr>
<tr>
<td>Silver</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Steel sheet</td>
<td>26 or more</td>
<td>28 or more</td>
</tr>
<tr>
<td>Sheet for deep drawing</td>
<td>30~35</td>
<td>28~32</td>
</tr>
<tr>
<td>Sheet for bending parts</td>
<td>27~36</td>
<td>33~44</td>
</tr>
<tr>
<td>Punching tip</td>
<td>23</td>
<td>32</td>
</tr>
<tr>
<td>Steel</td>
<td>0.1% C</td>
<td>0.3% D</td>
</tr>
<tr>
<td></td>
<td>0.3% D</td>
<td>0.3% C</td>
</tr>
<tr>
<td></td>
<td>0.3% C</td>
<td>0.3% D</td>
</tr>
<tr>
<td></td>
<td>0.6% C</td>
<td>0.6% D</td>
</tr>
<tr>
<td></td>
<td>0.8% C</td>
<td>0.8% C</td>
</tr>
<tr>
<td>Steel</td>
<td>72</td>
<td>90</td>
</tr>
<tr>
<td>Silicon steel sheet</td>
<td>45</td>
<td>56</td>
</tr>
<tr>
<td>Stainless steel sheet</td>
<td>53</td>
<td>66</td>
</tr>
<tr>
<td>Nickel</td>
<td>25</td>
<td>44</td>
</tr>
<tr>
<td>Leather</td>
<td>0.6~0.8</td>
<td>0</td>
</tr>
<tr>
<td>Microl</td>
<td>0.5 mm thick</td>
<td>0</td>
</tr>
<tr>
<td>Fiber</td>
<td>2 mm thick</td>
<td>5</td>
</tr>
<tr>
<td>Birch wood</td>
<td>9~18</td>
<td>3</td>
</tr>
<tr>
<td>(SI)</td>
<td>1.044</td>
<td>(Schuler, Bliss)</td>
</tr>
</tbody>
</table>

From Fig. 2, we see that when \( \rho \) is 1.1 kgf/mm², there is the possibility of fracture occurring with an SKD11 punch at approximately 9,000 shots. When the material is changed to SKH51, this increases to approximately 40,000 shots. The possibility for the jector punch is found in the same way. Because the cross-section area is smaller, the jector tip will fracture at approximately 5,000 shots. Fracture will not occur if the stress applied to the punch during use is less than the maximum allowable stress for that punch material.

(Consider this to be only a guide however, because the actual value depends on variations in the the die accuracy, die structure, and punched material, as well as the surface roughness, heat treatment, and other conditions of the punch.)
5. Flange fractures

As shown on P.1097, flange fractures are thought to be caused by tensile force generated by elastic waves which occur during punching (at breakthrough, tensile force equivalent to the punching load is applied to the punch), and by stress concentration.

Methods for preventing flange fractures include the following.
1. Increase the radius under the flange in order to relieve the concentration of stress. (Use a punch for heavy load.)
2. Increase the strength of the flange to a value higher than the punch tip.
   Here we will use method 2 to find the optimum shank diameter that will not produce flange fractures.

### Finding the optimum shank diameter by calculation

**Punching load P exerted on the punch is the following.**

\[ P = \pi \cdot d^2 \cdot e \]

The maximum allowable stress \( \sigma_r \) on the flange is the following.

(a) For a shoulder punch,

\[ \sigma_r = \frac{4 \cdot P}{\pi \cdot d^2} \cdot \frac{d^2}{D^2} \]

(b) For a jector punch

\[ \sigma_r = \frac{4 \cdot P}{\pi \cdot d^2} \cdot \frac{d^2}{(D^2-M^2)} \]

where \( D \) is Shank diameter

- Coefficient of stress concentration \( \alpha \) : 
  - For a shoulder punch, \( \alpha = \frac{1}{3} \)
  - For a jector punch, \( \alpha = \frac{1}{2} \)
  - For a punch for heavy load, \( \alpha = \frac{2}{3} \)
  - For tapered head punch, \( \alpha = 1.6 \)

Find the strength of the flange when the punching conditions are the same as in Example 1.

**Example 1**

(a) In the case of shoulder punch SPAS6—50—P2.8:

\[ \sigma = 4 \times 675 \times 3 \times 1.6 \times 671 \text{ kgf/mm}^2 \]

(b) In the case of jector punch SAJAS6—50—P2.8:

\[ \sigma = 4 \times 675 \times 5.6 \times (6.7^2 - 3) \times 159 \text{ kgf/mm}^2 \]

**Finding the optimal shank diameter from the diagram**

Punching conditions : Use the following formula to convert punch tip \( \varphi = 12.8 \text{ W} = 10.6 \text{ to } \varphi \text{ d value.} \)

\[ \varphi = \left( \frac{2 \cdot (P - W)}{W} \right) \frac{1}{\alpha} \]

\[ = \left( \frac{2 \cdot (12.8 - 10.6)}{10.6} \right) \frac{1}{\alpha} \]

\[ = 12 \text{ mm} \]

Sheet thickness \( t = 4 \text{ mm} \)

Shearing resistance \( e = 50 \text{ kgf/mm}^2 \)

In order to find the optimal shank diameter for \( 10^8 \) shots, follow the steps below.

**Survival of punch tip**

- a) Find the point a where the sheet thickness \( t \) and shearing resistance \( e \) intersect.
- b) Find point b by extending a line to the right from point a until it intersects the diameter of the punch tip.
  - Because Point b is below the line indicating \( 10^8 \) shots, both SKH and SKD punches will be capable of enduring a minimum of \( 10^8 \) shots.

**Selection of shank diameter**

- c) Find Point c by extending a line to the right from Point a until it intersects the punch tip diameter.
- d) Find Points d and d’ by extending a line down from Point c until it intersects the lines indicating \( 10^8 \) shots (line for standard, line for thick sheets).
- e) Find the shank diameter by extending lines to the right from Points d and d’.
  - Because 14.0 is indicated for standard punches (SKH), select a shank diameter of \( \varphi 16 \).
  - Because 11.8 is indicated for punches for heavy load (SKH), select a shank diameter of \( \varphi 13 \).

Note: This selection table was prepared based on the results of tensile and compression fatigue tests. Because the data may differ somewhat from the actual punching conditions, please use this table only as an approximate guide.
5. Flange fractures

As shown on P.1087, flange fractures are thought to be caused by tensile force generated by elastic waves which occur during punching (at breakthrough, tensile force equivalent to the punching load is applied to the punch), and by stress concentration.

Methods for preventing flange fractures include the following.

1. Increase the radius under the flange in order to relieve the concentration of stress. (Use a punch for heavy load.)
2. Increase the strength of the flange to a value higher than the punch tip.

Here we will use method 2 to find the optimum shank diameter that will not produce flange fractures.

### Finding the optimum shank diameter by calculation

<table>
<thead>
<tr>
<th>Punching load P exerted on the punch is the following.</th>
<th>A: Cross section area of flange [mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P = ( \sigma \cdot d \cdot \pi )</td>
<td>(a) For a shoulder punch, ( A_1 = \pi D^2/4 )</td>
</tr>
<tr>
<td>The maximum allowable stress ( \sigma_m ) on the flange is the following.</td>
<td>D : Shank diameter</td>
</tr>
<tr>
<td>(a) For a shoulder punch, ( \sigma_m = 4P \cdot \pi / A_1 )</td>
<td>(b) For a shoulder punch, ( \sigma_m = (D^2 - D^3) \cdot \pi / 4 )</td>
</tr>
<tr>
<td>(b) For a jector punch</td>
<td>(b) For a jector punch, ( \sigma_m = 4P \cdot \pi / (D^2 - D^3) )</td>
</tr>
</tbody>
</table>

**Example 6**

(a) In the case of shoulder punch SPAS6—50—P2.8:

\[ \sigma_m = 4 \times 675 \times 3/\pi \cdot 0.006 = 71.6 \text{ kgf/mm}^2 \]

Flange fracture will not occur because the stress is less than the stress applied to the punch tip in Example 2 of 110 kgf/mm².

(b) In the case of jector punch SJA6—50—P2.8:

\[ \sigma_m = 4 \times 675 \times 5.6 \times (0.006 - 0.003) = 159 \text{ kgf/mm}^2 \]

Fracture occurs from the flange because the stress is larger than the stress applied to the punch tip in Example 2 of 117 kgf/mm².

When the shank diameter is 8 mm, \( \sigma_m = 90 \text{ kgf/mm}^2 \), which does not cause flange fractures. (Considering the figure showing the fatigue strength of tool steel, the flange will break after about 50,000 shots.)

### Finding the optimal shank diameter from the diagram

Punching conditions: Use the following formula to convert punch tip P = 12.8 W = 10.6 to a \( \phi \) d value.

\[ \phi d = \left( \frac{2(P - W) + W_a}{W_a} \right) \pi \]

Sheer strain: \( \tau = 0.05 \text{ kgf/mm}^2 \)

In order to find the optimal shank diameter for 10⁶ shots, follow the steps below.

**Durability of punch tip**

- Find the point where the sheet thickness and the shear strain intersect.
- Find the point right or left of the point until it intersects the diameter of the punch tip.
- Because Point b is below the line indicating 10⁶ shots, both SKH and SKD punches will be capable of enduring a minimum of 10⁶ shots.

**Selection of shank diameter**

- Find Point c by extending a line from Point a until it intersects the punch tip diameter.
- Find Points d and d' by extending a line down from Point c until it intersects the lines indicating 10⁶ shots (line for standard, line for thick sheet).
- Find the shank diameter by extending lines to the right from Points d and d'.
- Because 14.0 is indicated for standard punches (SKH), select a shank diameter of \( \phi 16 \).
- Because 11.8 is indicated for punches for heavy load (SKD), select a shank diameter of \( \phi 13 \).

Note: This selection table was prepared based on the results of tensile and compression fatigue tests. Because the data may differ somewhat from the actual punching conditions, please use this table only as an approximate guide.