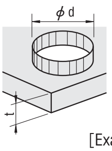
CALCULATION OF PUNCH STRENGTH①

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]



$P = \ell t \tau$ .... (1)

ℓ : Pinching profile length [mm]
(For a round punch, $\ell = \pi d$)
t : Material thickness [mm]
τ : Material shearing resistance [kgf/mm²]
($\tau \fallingdotseq 0.8 \times$ Tensile strength σ_B)

[Example 1] The maximum punching force P when punching a round hole of diameter 2.8 mm in a high-tensile steel sheet of thickness 1.2 mm (tensile strength 80 kgf/mm²), is the following. When $P = \ell t \tau$,
Shearing resistance $\tau = 0.8 \times 80$
$= 64$ [kgf/mm²]
$P = 3.14 \times 2.8 \times 1.2 \times 64 = 675$ kgf

[Table 1] Shearing resistance and tensile strengths of various materials

M	Shearing resistance τ (kgf/mm²) Soft	Shearing resistance τ (kgf/mm²) Hard	Tensile strength σ_B (kgf/mm²) Soft	Tensile strength σ_B (kgf/mm²) Hard
Lead	2～3	—	2.5～4	—
Tin	3～4	—	4～5	—
Aluminum	7～11	13～16	8～12	17～22
Duralumin	22	38	26	48
Zinc	12	20	15	25
Copper	18～22	25～30	22～28	30～40
Brass	22～30	35～40	28～35	40～60
Bronze	32～40	40～60	40～50	50～75
Nickel silver	28～36	45～56	35～45	55～70
Silver	19	—	26	—
Hot rolled steel sheet (SPH1～8)	26 or more		28 or more	
Cold rolled steel sheet (SPC1～3)	26 or more		28 or more	
Steel sheet for deep drawing	30～35		28～32	
Steel sheet for building structures (SS330)	27～36		33～44	
Steel sheet for building structure (SS400)	33～42		41～52	
Steel 0.1% C	25	32	32	40
〃 0.2% C	32	40	40	50
〃 0.3% C	36	48	45	60
〃 0.4% C	45	56	56	72
〃 0.6% C	56	72	72	90
Steel 0.8% C	72	90	90	110
〃 1.0% C	80	105	100	130
Silicon steel sheet	45	56	55	65
Stainless steel sheet	52	56	66～70	—
Nickel	25	—	44～50	57～63
Leather	0.6～0.8		—	
Mica 0.5 mm thick	8		—	
〃 2 mm thick	5		—	
Fiber	9～18		—	
Birch wood	2		—	

＊{N}＝kgf×9.80665 (Schuler, Bliss)

■2. Fracture of punch tip

• Stress applied to punch tip σ [kgf/mm²]

$\sigma = P/A$

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

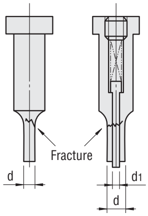
(a) For shoulder punch

$\sigma_S = 4 t \tau / d$ .... (2)

(b) For jector punch

$\sigma_J = 4 d t \tau / (d^2 - d_1^2)$ .... (3)

(a) Shoulder punch (b) Jector punch



[Fig. 1] Fracture of punch tip

[Example 2] Find the possibility of punch tip fracture when shoulder punch SPAS6—50—P2.8 and Jector punch SJAS6—50—P2.8 (d_1 dimension = 0.7, as shown on P. 186) are used. (Punching conditions are the same as in Example 1.)

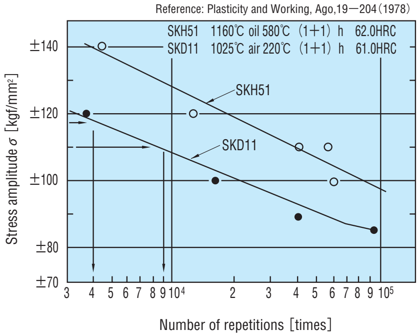
(a) For the shoulder punch, from Formula (2):
$\sigma_S = 4 \times 1.2 \times 64 / 2.8 = 110$ kgf/mm²

(b) For the jector punch, from Formula (3):
$\sigma_J = 4 \times 2.8 \times 1.2 \times 64 / (2.8^2 - 0.7^2)$
$= 117$ kgf/mm²

From Fig. 2, we see that when σ_S is 110 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 punch 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 varies depending 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.)

[Fig. 2] Fatigue characteristics of tool steel

Reference: Plasticity and Working, Ago, 19—204 (1978)



■3. Minimum punching diameter

• Minimum punching diameter: dmin.

$d_{min} = 4t\tau/\sigma$

σ : Fatigue strength of tool steel [kgf/mm^2]

[Example 3] The minimum punching diameter that is possible when punching 100,000 shots or more in SPCC of thickness 2 mm with an SKH51 punch is the following.

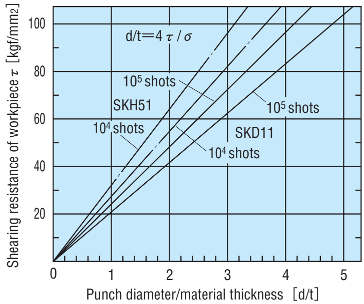
$d_{min} = 4t\tau/\sigma$ ………… (4)

$= 4\times2\times26/97$

$\fallingdotseq 2.1\text{mm}$ Fatigue strength for SKH51 at 100,000 shots:

$\sigma = 97$ kgf/mm^2 (from Fig. 2) $\tau = 26$ kgf/mm^2 (from Table 1)

[Fig. 3] Punching limit



■4. Fracture due to buckling

• Buckling load P [kgf]

$P = n\pi^2 EI/\ell^2$ ……………… (5)

$\ell = \sqrt{n\pi^2 EI/P}$ ……………… (6)

n : Coefficient n=1 : Without stripper guide

n=2 : With stripper guide

I : Second moment of inertia [mm^4]

For a round punch, $I = \pi d^4/64$

ℓ : Punch tip length [mm]

E : Young´s modulus [kgf/mm^2]

SKD11 : 21000
SKH51 : 22000
HAP40 : 23000
V30 : 56000

As indicated by Euler´s formula, steps which can be take to improve buckling strength P 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 4] Calculate the full length of the punch which will not produce buckling when a ϕ8 hole is punched in stainless steel SUS304 (sheet thickness 1 mm, tensile strength $\sigma_b = 60$ kgf/mm^2) with a straight punch (SKD11).

From Formula (6): $\ell = \sqrt{n\pi^2 EI/P}$

$= \sqrt{2\times\pi^2\times21000\times201/1206}$

$= 262$ mm

If the safety factor is 3, then

$\ell = 262/3 = 87$ mm

Punching force $P = \pi d t \tau$

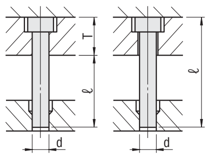
$= \pi\times8\times1\times0.8\times60$

$= 1206$ kgf

Second moment of inertia $I = \frac{\pi d^4}{64} = \frac{\pi 8^4}{64}$

$= 201\text{mm}^4$

With stripper guide : n=2



Based on punch plate Based on stripper

If the punch plate sheet thickness t is 20 mm, then buckling can be prevented by using a punch of total length 107 mm or less. For a punch based on the stripper plate (punch plate tip is guided by the clearance), the full length should be 87 mm or less.

[Example 5] The buckling load P when a SHAL5—60—P2.00—BC20 punch is used without a stripper guide is the following.

$P = n\pi^2 EI/\ell^2$

$= 1\times\pi^2\times22000\times0.785/20^2$

$= 426$ kgf

If the safety factor is 3, then

$P = 426/3 = 142$ kgf

∴ Buckling will not occur at a punching force of 142 kgf or less.

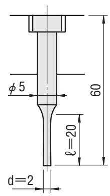
Punch material : SKH51

$E = 22000$ kgf/mm^2

$I = \frac{\pi d^4}{64} = \frac{\pi 2^4}{64}$

$= 0.785$ mm^4

Without stripper guide : n=1



[Fig.4] Buckling of 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.

$P = \pi d t \tau$

The maximum allowable stress σ_w on the flange is the following.

(a) For a shoulder punch,

$\sigma_w = P\alpha / A_t$

$= 4P\alpha / \pi D^2$

(b) For a jector punch

$\sigma_{wJ} = 4P\alpha / \pi (D^2 - M^2)$

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

A_t: Cross section area of flange [mm^2]

(a) For a shoulder punch,

$A_t = \pi D^2/4$

(b) For a jector punch

$A_t = \pi (D^2 - M^2)/4$

D : Shank diameter

α: Coefficient of stress concentration

(a) For a shoulder punch, $\alpha \fallingdotseq 3$

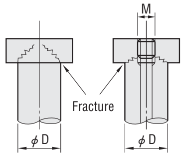
For a punch for heavy load, $\alpha \fallingdotseq 2$

For tapered head punch, $\alpha \fallingdotseq 1.6$

(b) For a jector punch, $\alpha \fallingdotseq 5$

[**Fig. 5**] Flange fracture

(a) Shoulder punch (b) Jector punch



[Example 6] (a) In the case of shoulder punch SPAS6—50—P2.8 :

$\sigma_w = 4 \times 675 \times 3 / \pi \cdot 6^2 = 71.6$ kgf/mm²·········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 SJAS6—50—P2.8 :

$\sigma_{wJ} = 4 \times 675 \times 5 / \pi (6^2 - 3^2) = 159$ kgf/mm²···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 8mm, $\sigma_{wJ} = 90$kgf/mm², which does not cause flange fractures. (Considering from the figure showing the fatigue strength of tool steel, the flange will break after about 50,000 shots.)

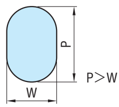
●Finding the optimal shank diameter from the diagram

Punching conditions : Use the following formula to convert punch tip P=12.8 W=10.6 to a φd value.

$\phi d = [2(P - W) + W\pi]/\pi$

$= [2(12.8 - 0.6) + 10.6\pi]/\pi$

$= 12$ mm



Sheet thickness t=4 mm Shearing resistance $\tau = 50$ kgf/mm²

In order to find the optimal shank diameter for 10^4 shots, follow the steps below.

Durability of punch tip (fracture) [Fig. 6]

a) Find the point a where the sheet thickness t and shearing resistance τ intersect.

b) Find point b by extending a line to the left or right from point a until it intersects the diameter of the punch tip.

・ Because Point b is below the line indicating 10^5 shots, both SKH and SKD punches will be capable of enduring a minimum of 10^5 shots.

Selection of shank diameter [Fig. 7]

c) Find Point c by extending a line to the right from Point a until it intersects the punch tip diameter.

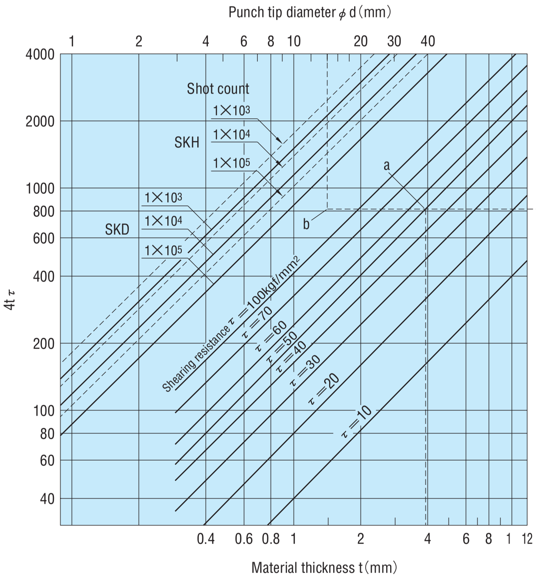
d) Find Points d and d′ by extending a line down from Point c until it intersects the lines indicating 10^4 shots (line for standard, line for thick sheets).

e) Find the shank diameter by extending lines to the right from Points d and d .

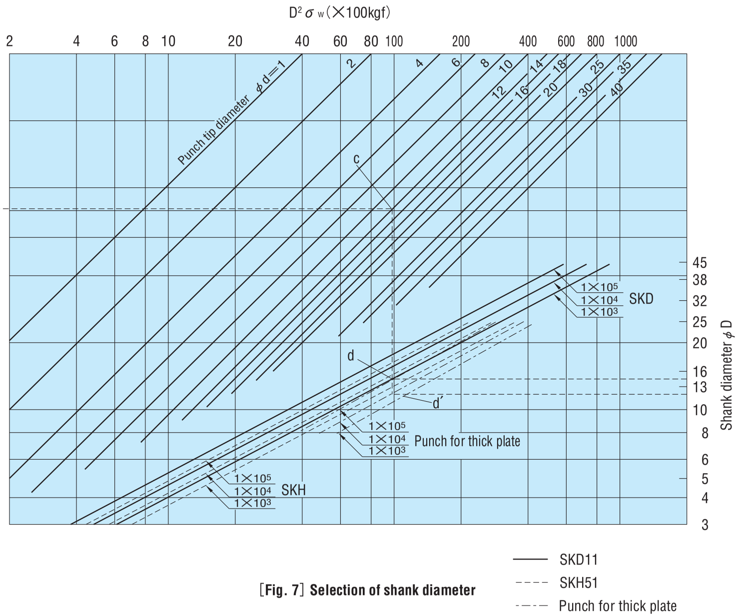
・ Because 14.0 is indicated for standard punches (SKH), select a shank diameter of φ16.

・ Because 11.8 is indicated for punches for heavy load (SKH), select a shank diameter of φ13.

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.



[Fig. 6] **Durability of punch tip (fracture)**



[Fig. 7] **Selection of shank diameter**