5. Gear design and strength

Iupital has good strength, durability, wear resistance, and chemical resistance, so can be used to each gear. Gear wreck will happen because of its tooth fatigue and tooth surface wear, so strength design from both side is necessary.

5.1 Gear design

5.1.1 Dedendum strength

Lewis formula (1) is generally employed for flexural stress on dedendum.

$W = S \cdot b \cdot m \cdot (y') \cdots\cdots\cdots\cdots\cdots (1)$

S : Flexural stress on dedendum (kg/mm2)

m : Module (mm)······Diametral pitch $Pd = \frac{25.4}{m}$

b : Face width (mm)

(y´) : Tooth form modulus (see table 5.1.1-1)

W : Pitch circumferential tangent load (kg)

Table 5.1.1-1 Tooth form modulus of spur gear

Pressure angle 20° standard gear						Pressure angle 14.5° standard gear					
Teeth numberz	y(y´)		z	y(y´)		Teeth numberz	y(y´)		z	y(y´)	
12	0.277	0.415	60	0.433	0.713	12	0.237	0.355	60	0.365	0.603
13	0.292	0.443	75	0.443	0.735	13	0.249	0.377	75	0.369	0.613
14	0.308	0.468	100	0.454	0.757	14	0.261	0.399	100	0.374	0.622
15	0.319	0.490	150	0.464	0.779	15	0.270	0.415	150	0.378	0.635
			300	0.474	0.801				300	0.385	0.650
16	0.325	0.503	Rack	0.484	0.823	16	0.279	0.430	Rack	0.390	0.660
17	0.330	0.512				17	0.288	0.446			
18	0.335	0.522				18	0.293	0.459			
19	0.340	0.534				19	0.299	0.471			
20	0.346	0.543				20	0.305	0.481			
21	0.352	0.553				21	0.311	0.490			
22	0.354	0.559				22	0.313	0.496			
24	0.359	0.572				24	0.318	0.509			
26	0.367	0.587				26	0.327	0.522			
28	0.372	0.597				28	0.332	0.534			
30	0.377	0.606				30	0.334	0.540			
34	0.388	0.628				34	0.342	0.553			
38	0.400	0.650				38	0.347	0.565			
43	0.411	0.672				43	0.352	0.575			
50	0.422	0.694				50	0.357	0.587			

5.1.2 Tooth surface strength

Damage phenomenon like pitching and wear will occur on tooth surface, and Hertz formula (2) is generally employed.

$$W=\sigma_{\alpha}^{2} b d_1 \frac{\sin 2\alpha}{2.8}\left(\frac{2Z_2}{Z_1+Z_2}\right)\left(\frac{1}{E_1}+\frac{1}{E_2}\right) \quad \cdots\cdots\cdots\cdots\cdots(2)$$

W : Pitch circumferential tangent load
b : Face width
d1 : Gear pitch circle diameter
α : Meshing pressure
Z1 : Gear teeth number
Z2 : Pinion teeth number
E1 : Gear longitudinal elastic modulus
E2 : Pinion longitudinal elastic modulus
$\sigma\alpha$: Allowable compressive stress

5.2 Tooth fatigue strength and surface pressure strength

Tooth fatigue failure, flexural stress that led to wear damage, and surface pressure will change by the difference of operational aspect.
Following are some factors that effect to tooth duration

1) Actual usage temperature
2) Existence of lubricity
3) Gear material used for power transmission
4) Operational aspect (continuous or intermittent operation)
5) Power transmission speed
6) Wear property of contacting face
7) Meshing ratio

so, overall consideration is necessary.
Figure 5.2-1 and 5.2-2 indicate gear fatigue endurance, and surface pressure strength.

Gear strength S-N curve

Assemblage of Iupital (No lubricant)

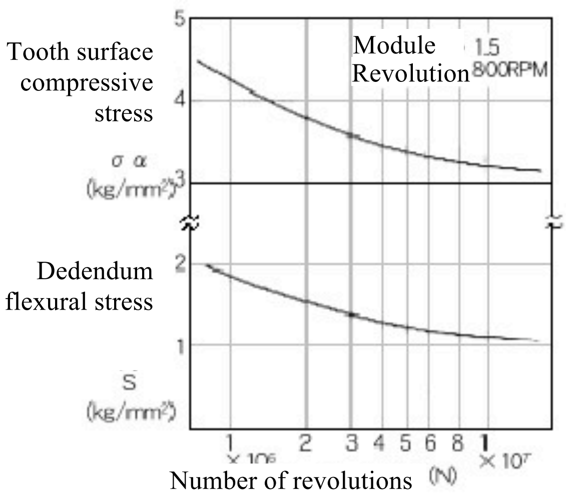


Figure 5.2-1 Relationship of gear strength and cycle

鋼歯車との組合せ

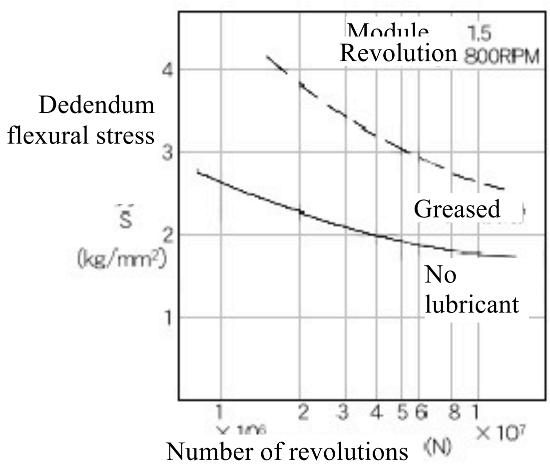


Figure 5.2-2 Relationship of gear strength and cycle

6. Joint

6.1 Metal insert

There is method that insert when molding, and method that insert after molding, but in this section, former insert method is going to be stated.

Result of inserting by brass insert clasp is indicated in Figure 6.1-2 to 6.1-4. The following will be obvious from these results.

1) Thickness ratio, pullout force, and rotary torque around insert clasp will become upward convex curve, and indicates peak in thickness ratio of about 2.0. This will decrease by material mechanical holding force degradation on the small thickness ratio side, and by sink effect of thickness direction on the bigger side.
2) Pullout force and rotary torque value will increase by thermal process. This is considered as heat shrinkage effect.
3) Holding force will widely increase by placing knurling groove.
4) Figure 6.1-5 indicates stress around insert clasp, calculated from pullout force value. This is calculated from next formula.

$$\sigma_{max}=FW/\pi D_s L\mu$$

σ_{max} : Maximum pullout stress(kg/cm2)、W : k_2+1/k_2-1
F : Pullout force(kg)、μ : Friction coefficient(0.15)
$k=D_h/D_s$(boss outer diameter/insert clasp diameter)
L : Insert clasp length (cm)

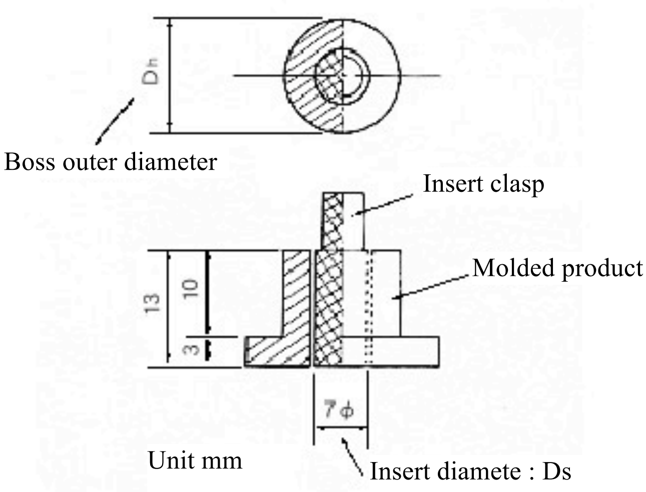
Points to look out about Iupital molding insert is crack generation around clasp. The following will be some causes of crack, so be careful.

1) Stress concentration by clasp sharp edge
2) Weld line
3) Stress increase by heat aging in usage environment

There is also a case that caused crack from knurl sharp edge weld part by thermal process in 75℃ for 3,000 to 4,000

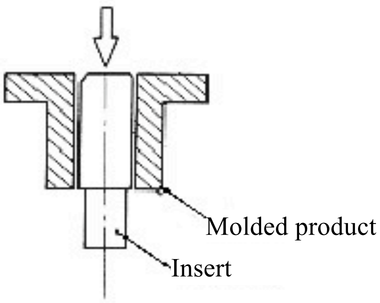
Figure 6.1-1　Insert molded product shape and insert holding force measurement method

(1) Test piece shape

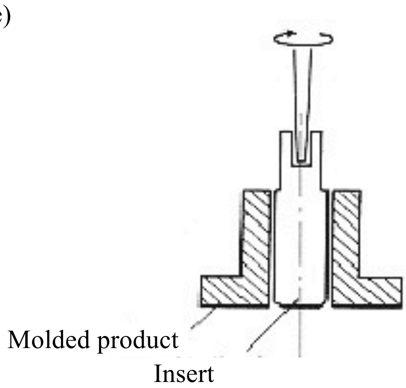


(2) Measurement method

i) Pullout force (axis direction holding force)



ii) Rotary torque (circumferential holding force)



Clasp holding condition in insert molding (insert clasp7mmϕ×13mmL brass)

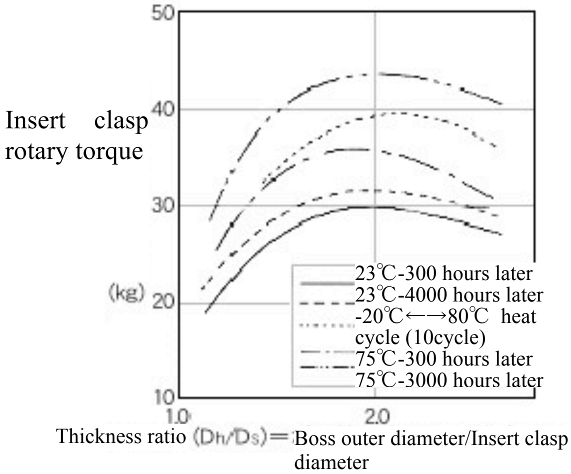


Figure 6.1-2 Insert clasp pullout force without knurl

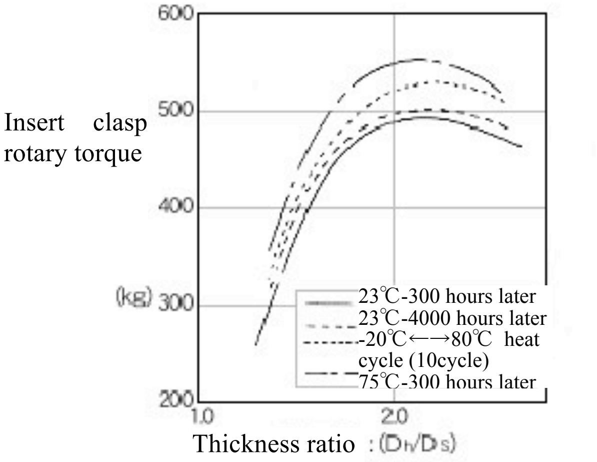
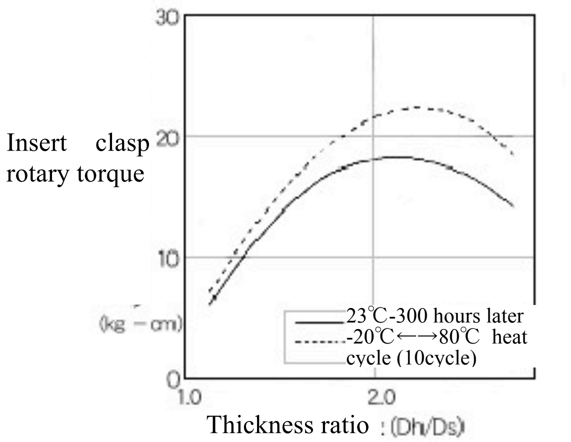


Figure 6.1-3 Insert clasp pullout force with knurl



Insert clasp rotary torque without knurl

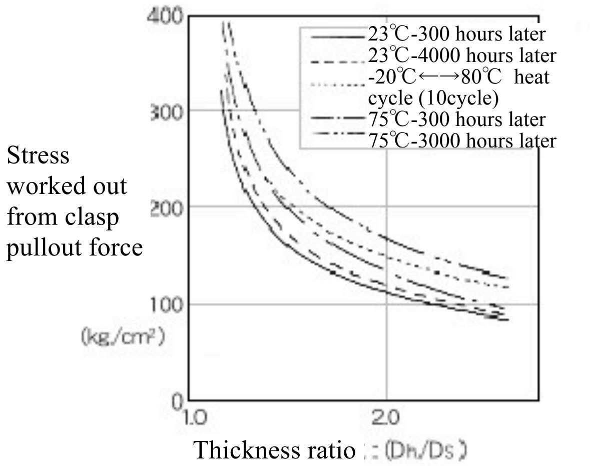


Figure 6.1-5 Stress in each thickness ratio

6.2 Fastening by self tap screw

Iupital self tap screw property is examined by changing prepared hole diameter (hang-up rate), boss outer diameter, and screw depth, of 3mm ϕ self tap screw, using Iupital test piece indicated in Figure 6.2-1. Hang-up rate here is calculated as below, though there is no accurate definition for self tap screw.

$$\text{Hang-up rate (\%)} = \frac{D(\text{Male screw outer diameter}) - d1(\text{Prepared hole diameter})}{D(\text{Male screw outer diameter}) - D1(\text{Male screw root diameter})}$$

Result is as indicated in Figure 6.2-2～6.2-5. Followings became obvious from the result.

1) Bigger the hang-up rate and screw depth is, bigger the screw pullout force and driving torque is.
2) If boss thickness become thicker, and the hang-up rate is big, pullout force and breakdown torque will be bigger.
3) Thermal process and heat cycle process will progress the breakdown torque and degrade loosening torque.

When fastening Iupital molded product by self tap screw, greater hang-up rate will increase the breakdown torque and pullout force, but driving torque will be bigger, and workability will be worse. Make the screw depth deeper if want to increase breakdown torque and pullout force without worsening workability. Boss part thickness should be more than 1/2 of screw outer diameter, but if it is too thick, sink will generate and degrades hang-up rate, so be careful.

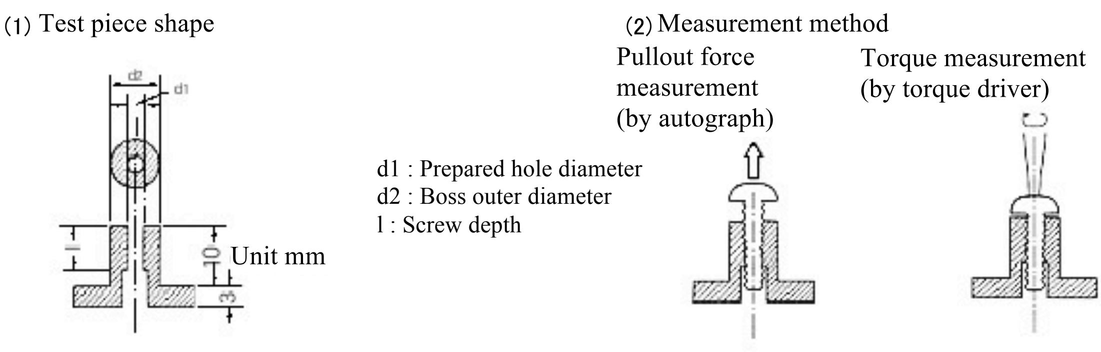
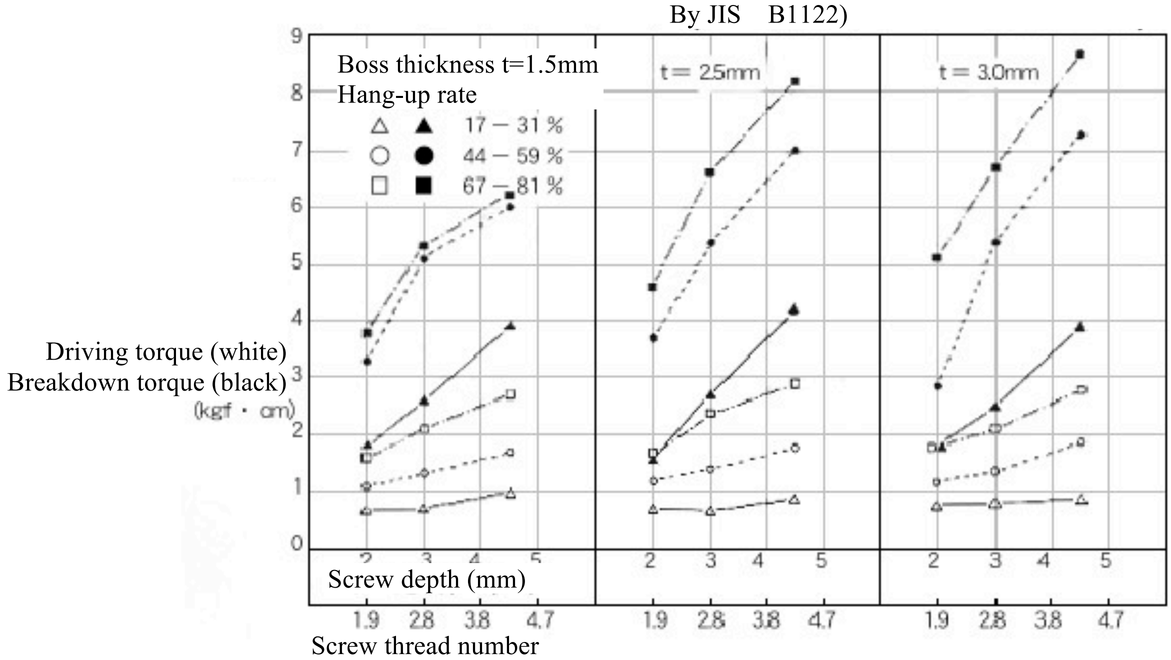


Figure 6.2-1 Self tap screw fastening

(1) Driving torque and breakdown torque

(screw: outer diameter 3mm cross-recessed tapping screw, with two types of end groove. By JIS B1122)



(2) Screw pullout force

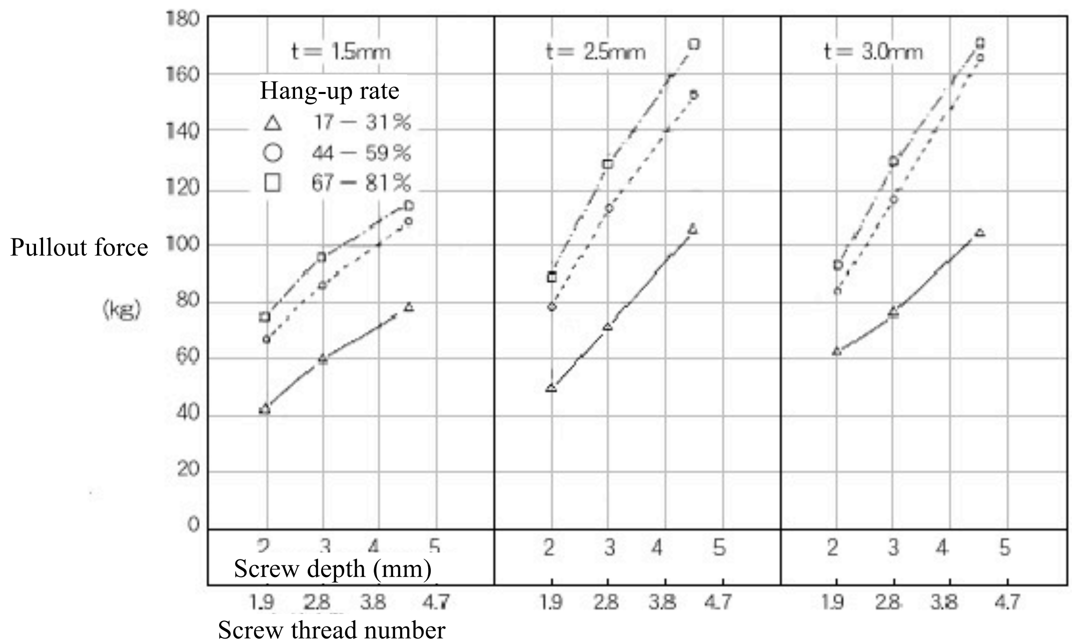
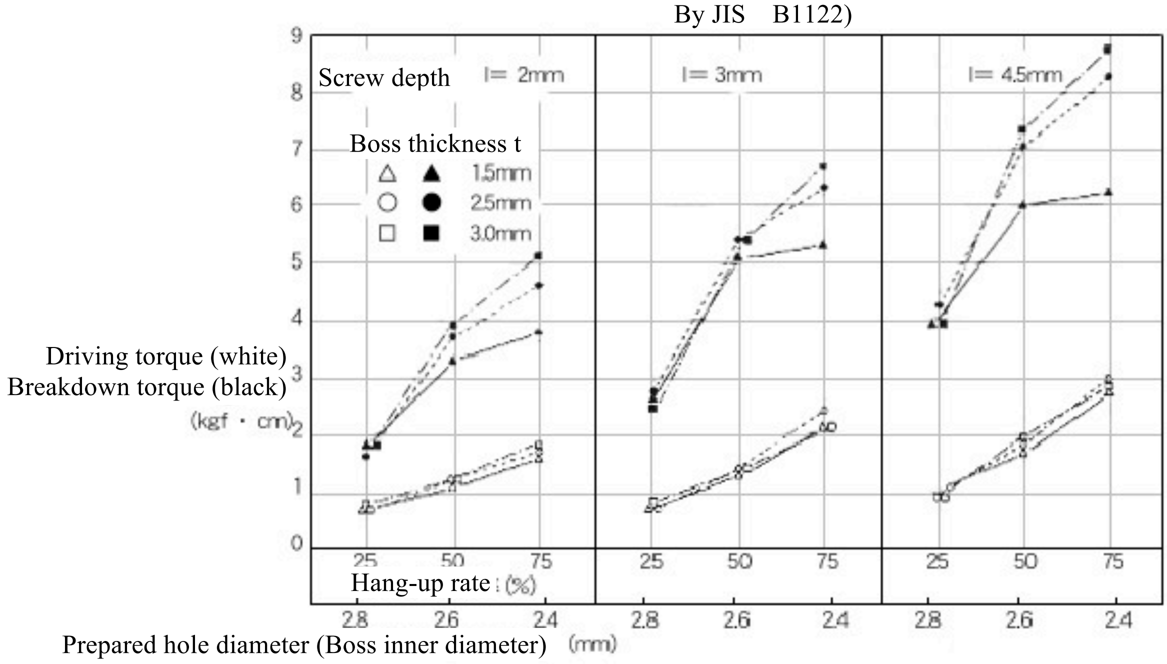


Figure 6.2-2 Fastening screw depth by self tap screw

(1) Driving torque and breakdown torque

(screw: outer diameter 3mm cross-recessed tapping screw, with two types of end groove. By JIS B1122)



(2) Screw pullout force

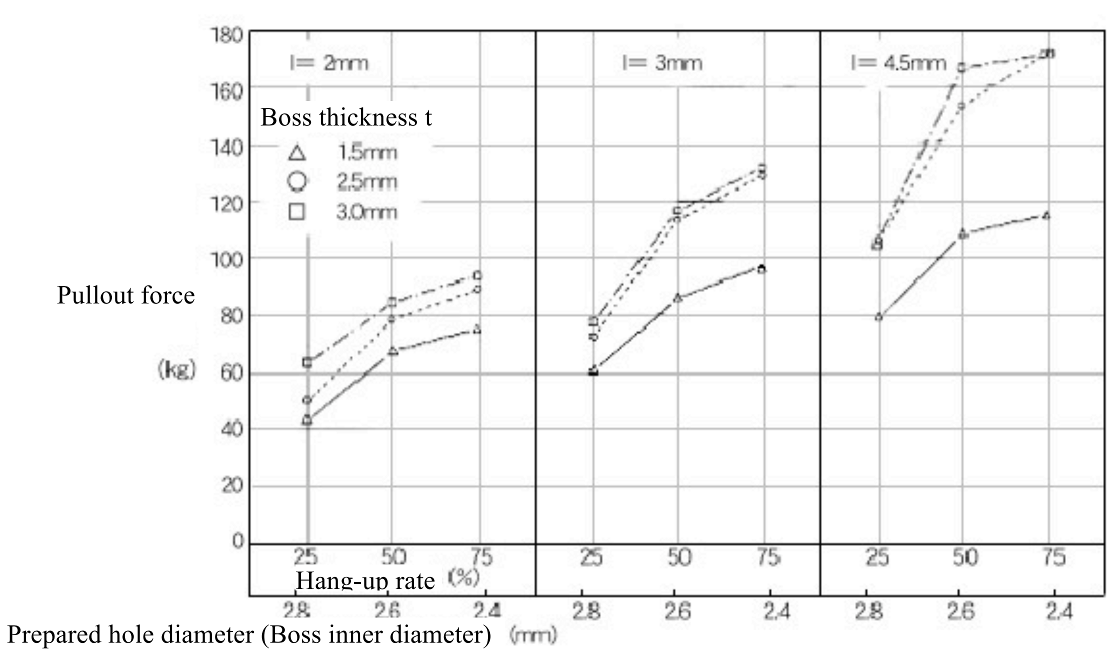
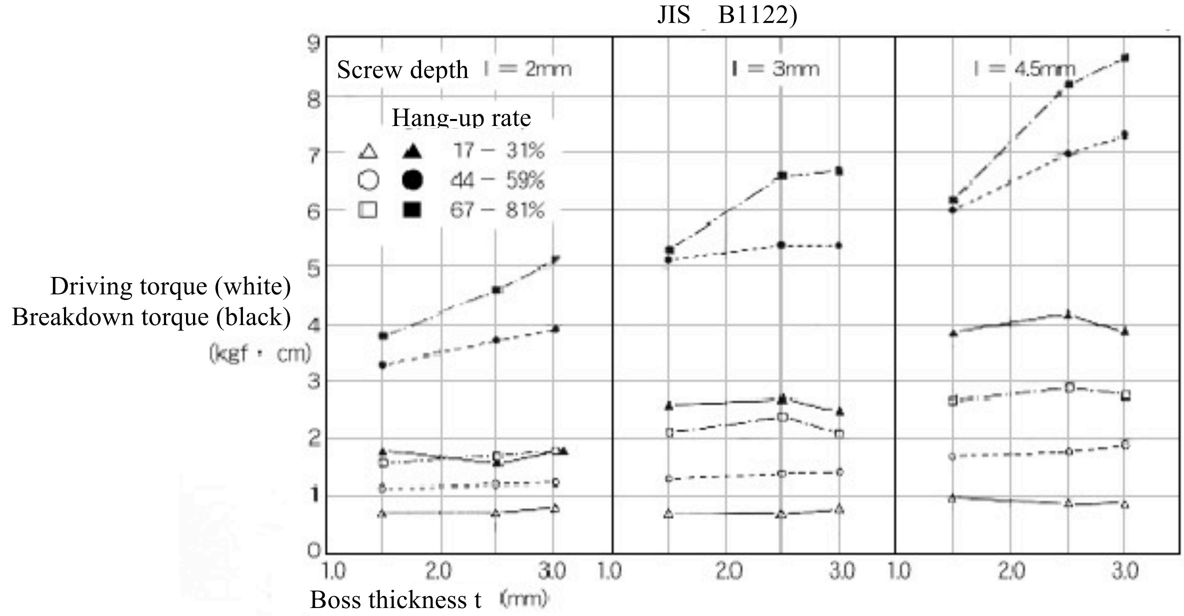


Figure 6.2-3 Effect of fastening prepared hole diameter (hang-up rate) by self tap screw

(1) Driving torque and breakdown torque (screw: outer diameter 3mm cross-recessed tapping screw, with two types of end groove. By JIS B1122)



(2) Pullout force of screw

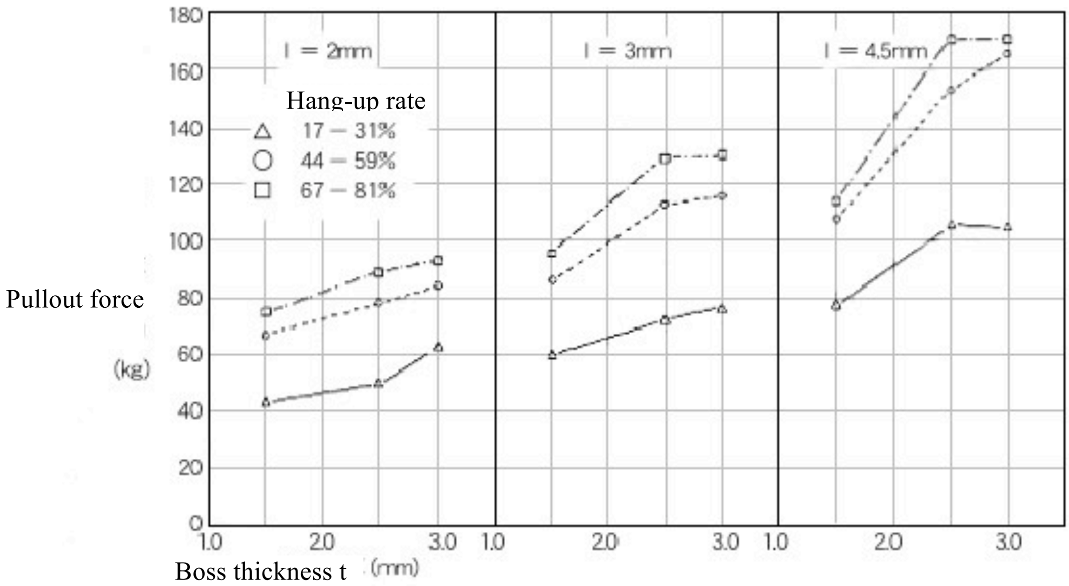


Figure 6.2-4 Effect of fastening boss thickness by self tap screw

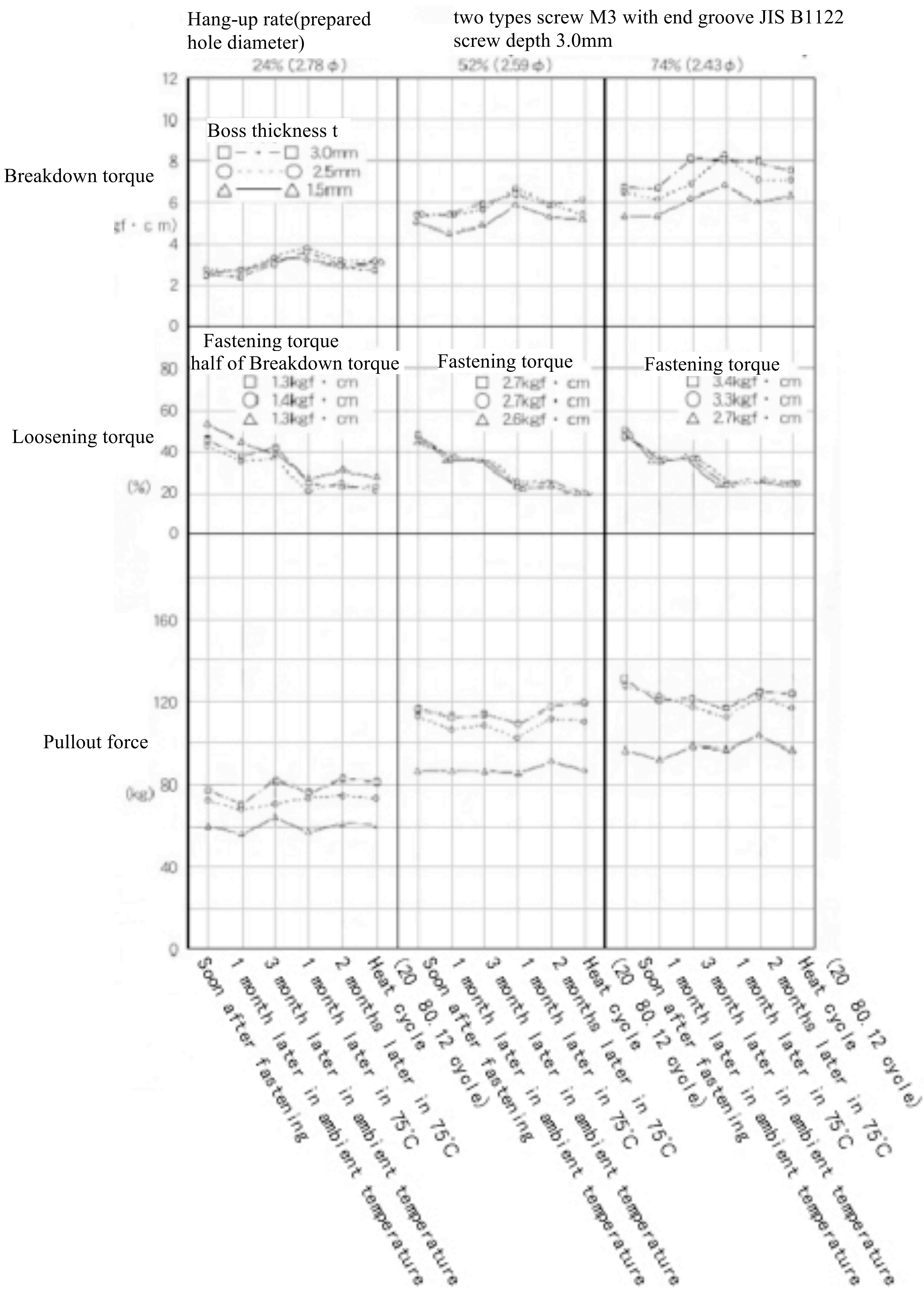


Figure 6.2-5 Long term fastening test of self tap screw

6.3 Fastening by metal machine screw

Change in loosening torque and fastening force after Iupital molded product fastened by metal machine screw as in Figure 6.3-1, is examined.

Fastening force Q generated on screw is calculated from torque T by following formula.

Here indicates relationship of fastening torque Tf and fastening force Qf when the code is +, and relationship of loosening torque Tr and fastening force Qr when the code is -.

d2 : effective diameter of screw

μ : friction coefficient of intermeshed screw thread (worked out as 0.20)

θ : screw thread angle

$\tan \rho = \mu / \cos \theta / 2$

P : pitch

β : lead angle of screw

μ n : friction coefficient of bearing surface (worked out as 0.15)

dn : average diameter of bearing surface $\left(\frac{B + d'}{2}\right)$

Figure 6.3-3～6.3-6 indicates result. As known from this result, loosening torque and fastening force will be decreased by stress relaxation after long term left. This tendency is especially noticeable under high temperature. Consequently, spring washer or other method will be necessary if the looseness is being problem. On the other hand, there was no cracks by thermal process or heat cycle process, around Iupital fastened part.

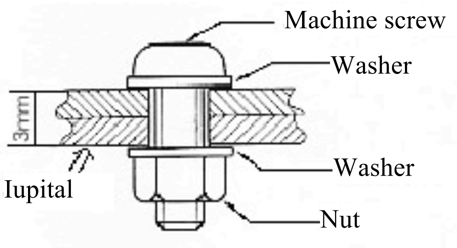


Figure 6.3-1 Fastening test method by metal machine screw

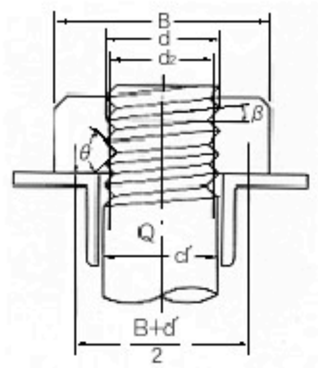


Figure 6.3-2 Fastening part figure

Fastening force will be insufficient if the fastening torque is too high, because it will cause deformation in Iupital fastened part. It is safe if the fastening torque is set within±20% from the standard value shown in table below, and tighten if there is a possibility to get loose, and loosen for better workability.

Table 6.3-1 Standard fastening torque of machine screw

Nominal designation of thread	M3	M4	M5	M6
Standard fastening torque kgf・cm	7.5	20	35	50

fasten in torque 5kgf・cm, loosening torque after process is indicated as pullout force (Qr) is indicated as
fasten in torque 75kgf・cm, loosening torque after process is indicated as pullout force (Qr) is indicated as
fasten in torque 10kgf・cm, loosening torque after process is indicated as pullout force (Qr) is indicated as

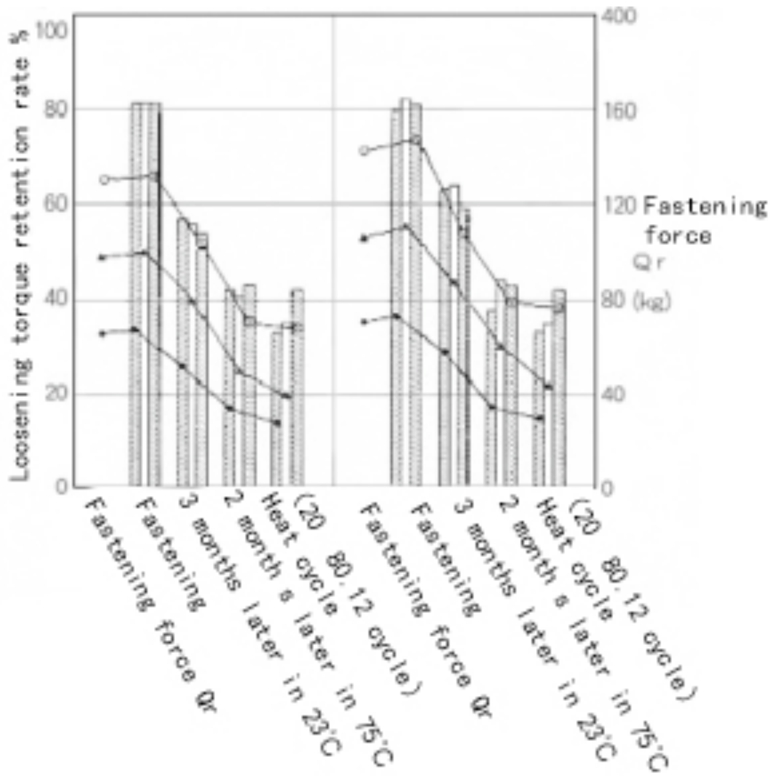


Figure 6.3-3 Loosening torque retention rate and fastening force of M3 machine screw after long term fastening

fasten in torque 10kgf・cm, loosening torque after process is indicated as , pullout force (Qr) is indicated as
fasten in torque 20kgf・cm, loosening torque after process is indicated as pullout force (Qr) is indicated as
fasten in torque 30kgf・cm, loosening torque after process is indicated as pullout force (Qr) is indicated as

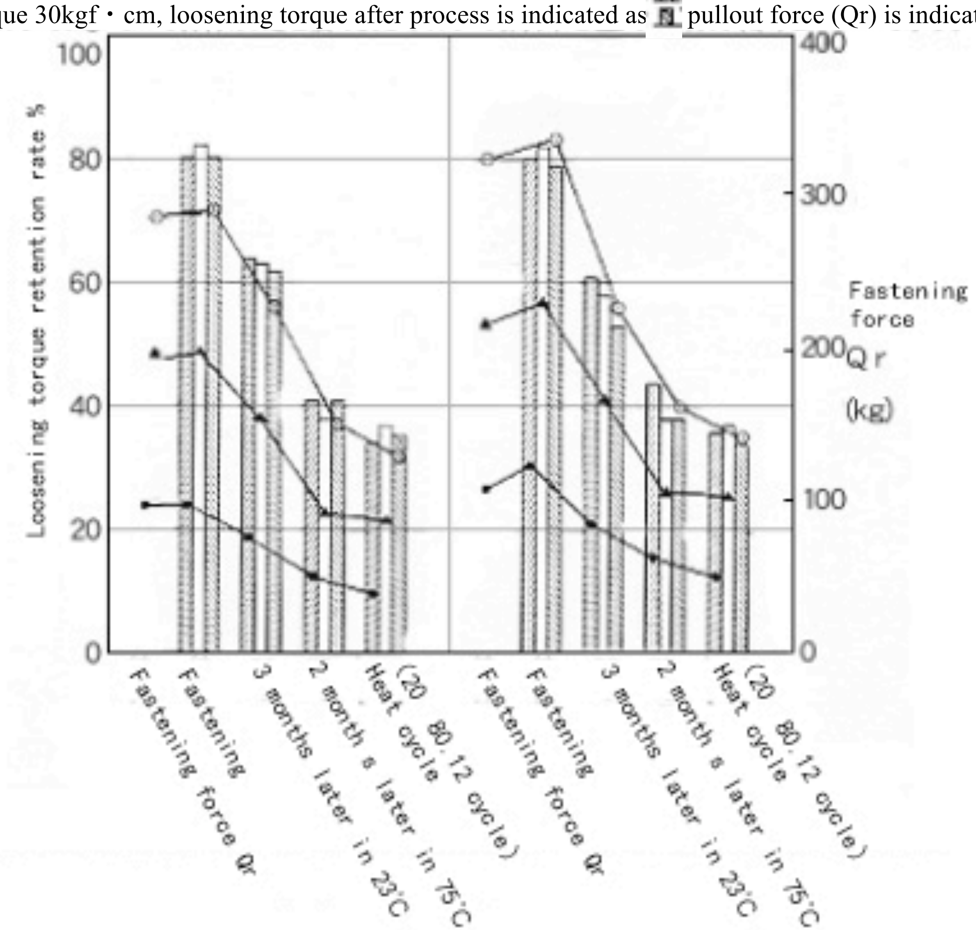


Figure 6.3-4 Loosening torque retention rate and fastening force of M4 machine screw after long term fastening

fasten in torque 20kgf・cm, loosening torque after process is indicated as , pullout force (Qr) is indicated as
fasten in torque 35kgf・cm, loosening torque after process is indicated as pullout force (Qr) is indicated as
fasten in torque 50kgf・cm, loosening torque after process is indicated as pullout force (Qr) is indicated as

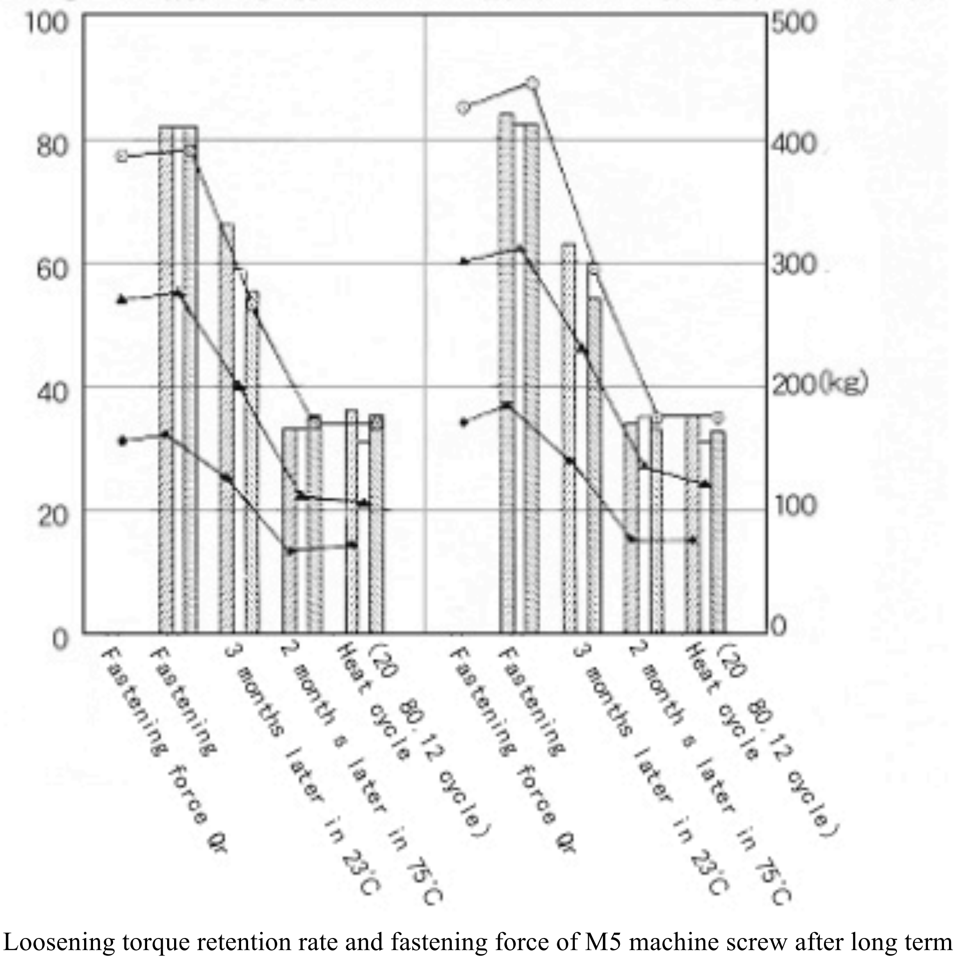


Figure 6.3-5 Loosening torque retention rate and fastening force of M5 machine screw after long term fastening

fasten in torque 20kgf・cm, loosening torque after process is indicated as , pullout force (Qr) is indicated as
fasten in torque 50kgf・cm, loosening torque after process is indicated as pullout force (Qr) is indicated as
fasten in torque 80kgf・cm, loosening torque after process is indicated as pullout force (Qr) is indicated as

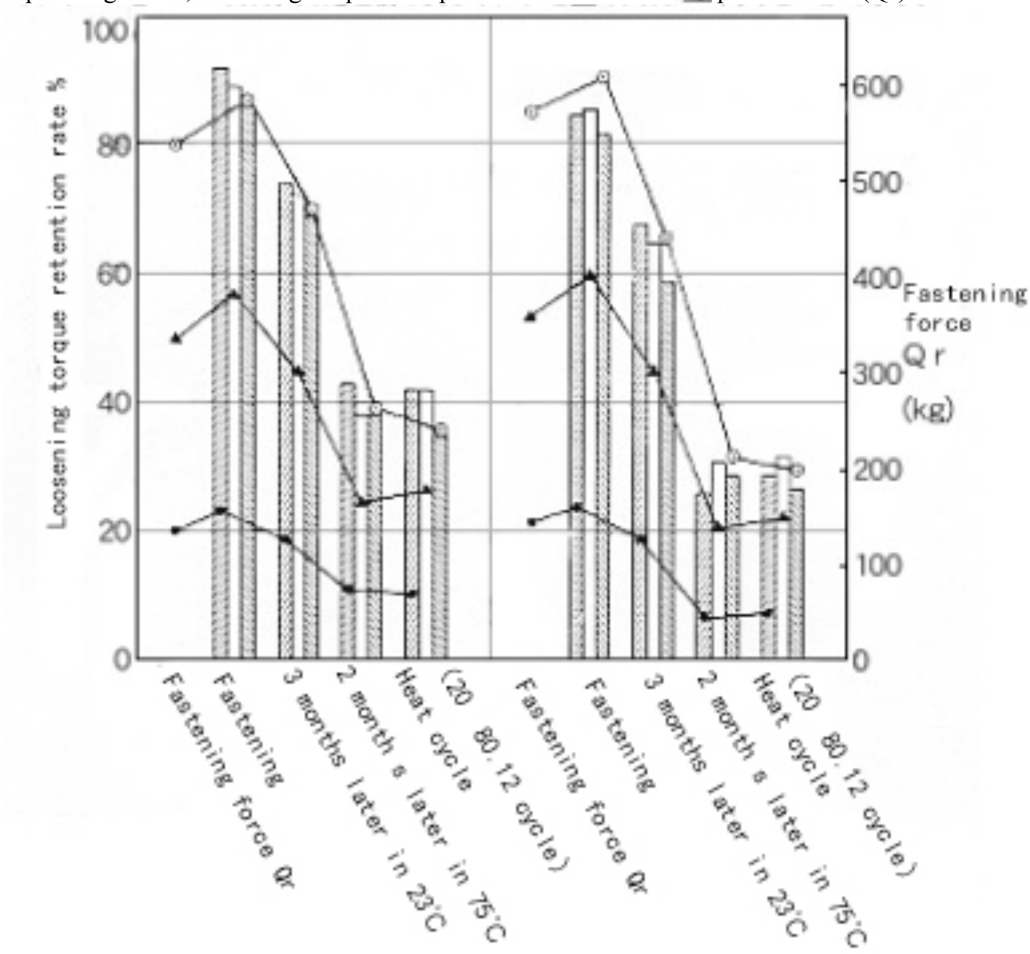


Figure 6.3-6 Loosening torque retention rate and fastening force of M6 machine screw after long term fastening

6.4 Ultrasonic jointing

As shown in Table 6.4-1, polyacetal ultrasonic jointing is relatively easy if took care of deposition machine power and joining area design. It is applicable to not only deposition transmitting, but also direct deposition, rivet, and insert.
As a Iupital ultrasonic jointing (deposition transmitting), test was conducted by using test piece like indicated in Figure 6.4-1. Result is as shown in Figure 6.4-2 and 6.4-3. As shown in this result, high strength can be gained if there is enough output power and pressure time. Also, detachment of deposition surface is indicated at low strength side, but maternal destruction is indicated at high strength side, which can be considered sufficient.

Table 6.4-1 Ultrasonic jointing property of plastic

Plastics	Transmittance	Direct	Rivet	Insert	Deposition condition
PolystyreneGP	Excellent	Excellent	Excellent	Excellent	Good acoustic property, less depression, great deposition, short solidification time
PolystyreneHI	Excellent→ Great	Excellent	Excellent	Excellent	Rubber content up to 30% (transmission) conformed to GP
AS	Excellent→ Great	Excellent	Excellent	Excellent	30% more depression compared to Polystyrene (GP)
ABS	Excellent→ Great	Excellent	Excellent	Excellent	Reformed by glass (15%) Deposited with AS, Polystyrene, and Acrylic
Polycarbonate	Excellent→ Great	Excellent	Excellent	Excellent	High energy required because of high softening temperature, good deposition with article soon after drying or injection
Nylon	Good	Great	Excellent	Excellent	Better deposition property with glass Better deposition property by drying
Polysulfone	Great	Great	Excellent	Excellent	
Polyacetal	Great	Great	Excellent	Excellent	High energy required
Acrylic	Excellent→ Great	Excellent	Excellent	Excellent	Deposited with AS and ABS
Polyphenylene oxide	Great	Great	Great	Excellent	High energy required
Polypropylene	Good	Excellent→ Great	Excellent	Excellent	Big depression, relatively thin (transmission)
Polyethylene	Good	Excellent→ Great	Excellent	Excellent	Longer vibration time because of large thermal conduction
Chloroethylene (hard)	Good	Excellent	Great	Great	Decompose by case
Acetate	Good	Great	Great	Great	Equalize stress distribution if many acetyl group

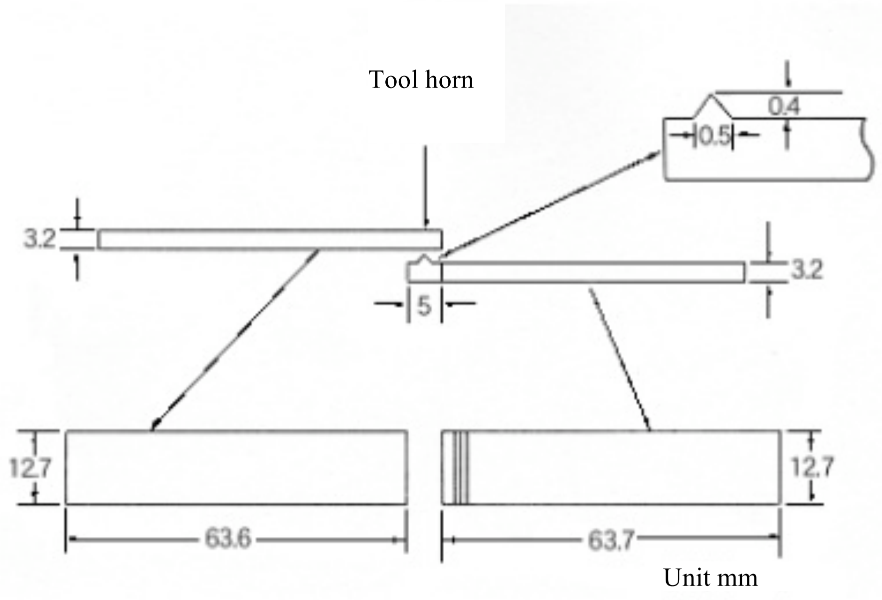


Figure 6.4-1　Ultrasonic deposition testing method

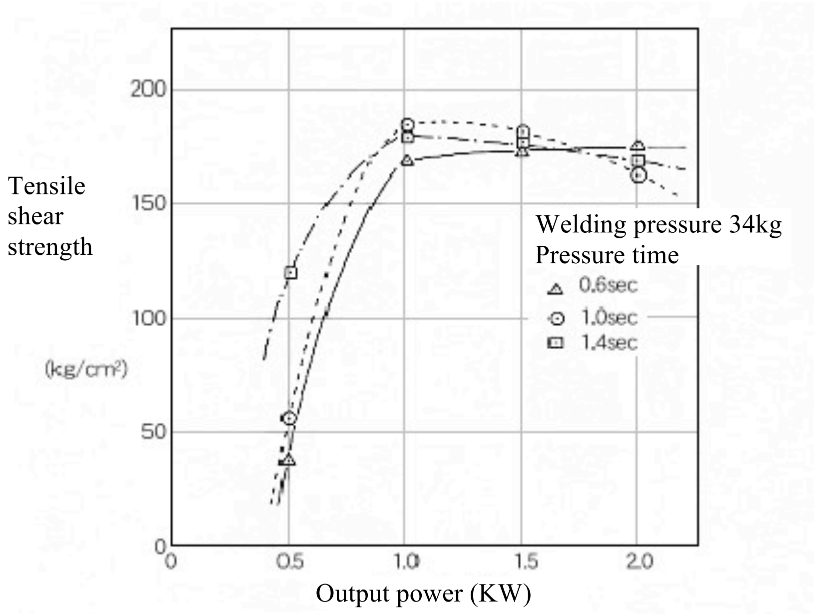


Figure 6.4-2 Effect of output power

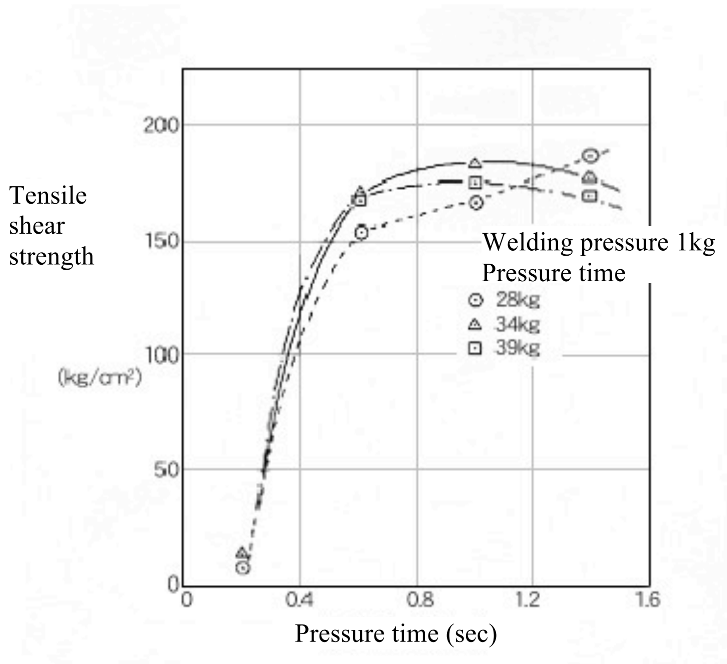


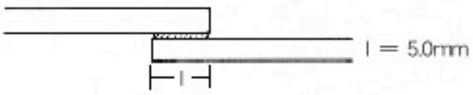
Figure 6.4-3 Effect of pressure time

6.5 Adhesion by bond

Iupital bond adhesion conducted in following method.
Test piece
Size (width) 20mm×(length)70mm
Thickness 1.0,2.0,3.0,5.0,8.0mm

Preparation of bonding plane
Degreasing only (acetone used)
Roughened (roughened by #120 endless polishing belt)

Joining method
Superposition



Collation

Result is indicated in Table 6.5-1. As shown in this table, cyanoacrylate and epoxy adhesion bond is relatively good for Iupical, if joining Iupital to Iupital. On the other hand, Iupital molded product surface lacks affinity, so adhesion strength will rise widely by chemically or physically roughening.

Table 6.5-1 Iupital joining by adhesion bond

(Unit kg/cm2)

Bond	Bonding plane process	Joining method				
		Superposition*				Collation**
		Test piece thickness tmm				
		1.0	2.0	3.0	5.0	8.0
Cyanoacrylate	Unprocessed	9	15	8	5	52
	Roughening #120	23	27	36	44	53
Epoxy	Unprocessed	9	15	20	18	36
	Roughening #120	19	25	28	28	57
Modified acrylic	Unprocessed	7	14	12	20	23
	Roughening #120	21	23	27	27	25
Rubber (chloroprene ruber)	Unprocessed	12	11	8	8	10
	Roughening #120	20	22	22	19	10

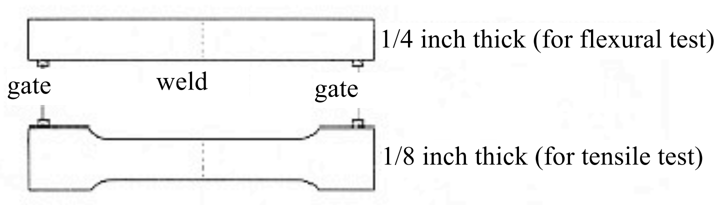
* Tensile shear strength
** Tensile strength

7. Weld strength

Molded products which are used as functional part or structural part, must have thread fastening hole, boss, and rib for reinforcement. Furthermore, resin flow will be complex by multipoint gate and thickness distribution, and will cause weld. It will cause stress concentration at external force loaded part, and will become weaker against impact and load, and could even end up with strength deterioration, so be careful.

Weld part tensile strength, elongation, and flexural strength retention rate is indicated in Figure 7-1

Test piece and weld location



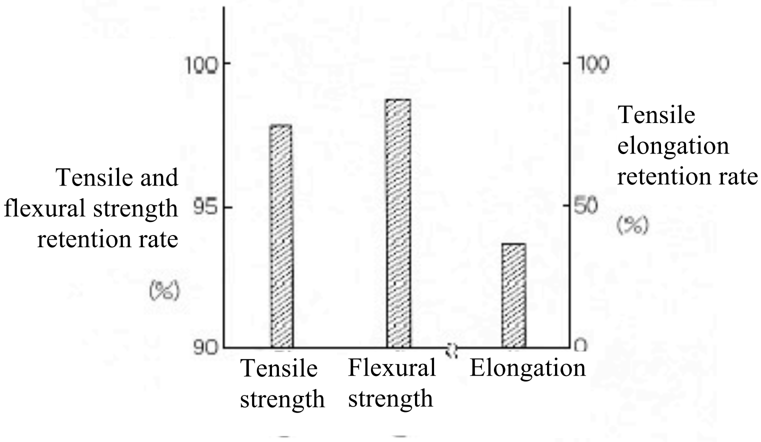


Figure 7-1 Weld strength