ＩＣＦＧ　鍛造製品特性サブグループ

第２回ワークショップ

テーマ　：　鍛　造　製　品　の　特　性

サブテーマ　：　高炭素クロム軸受鋼（ＳＵＪ２）の冷間鍛造

Cold Forging of High-carbon Chromium Bearing Steel (SUJ 2)

難加工材とされるＳＵＪ２を複雑形状、高精度に冷間鍛造で量産を可能にした技術を生産現場の経験から紹介する。

We succeeded in mass-producing the cold forgings of high-carbon chromium bearing steel (SUJ 2), known as a hardly machinable material, by realizing complex shape machining with high accuracy. The background is mainly explained based on field experience.

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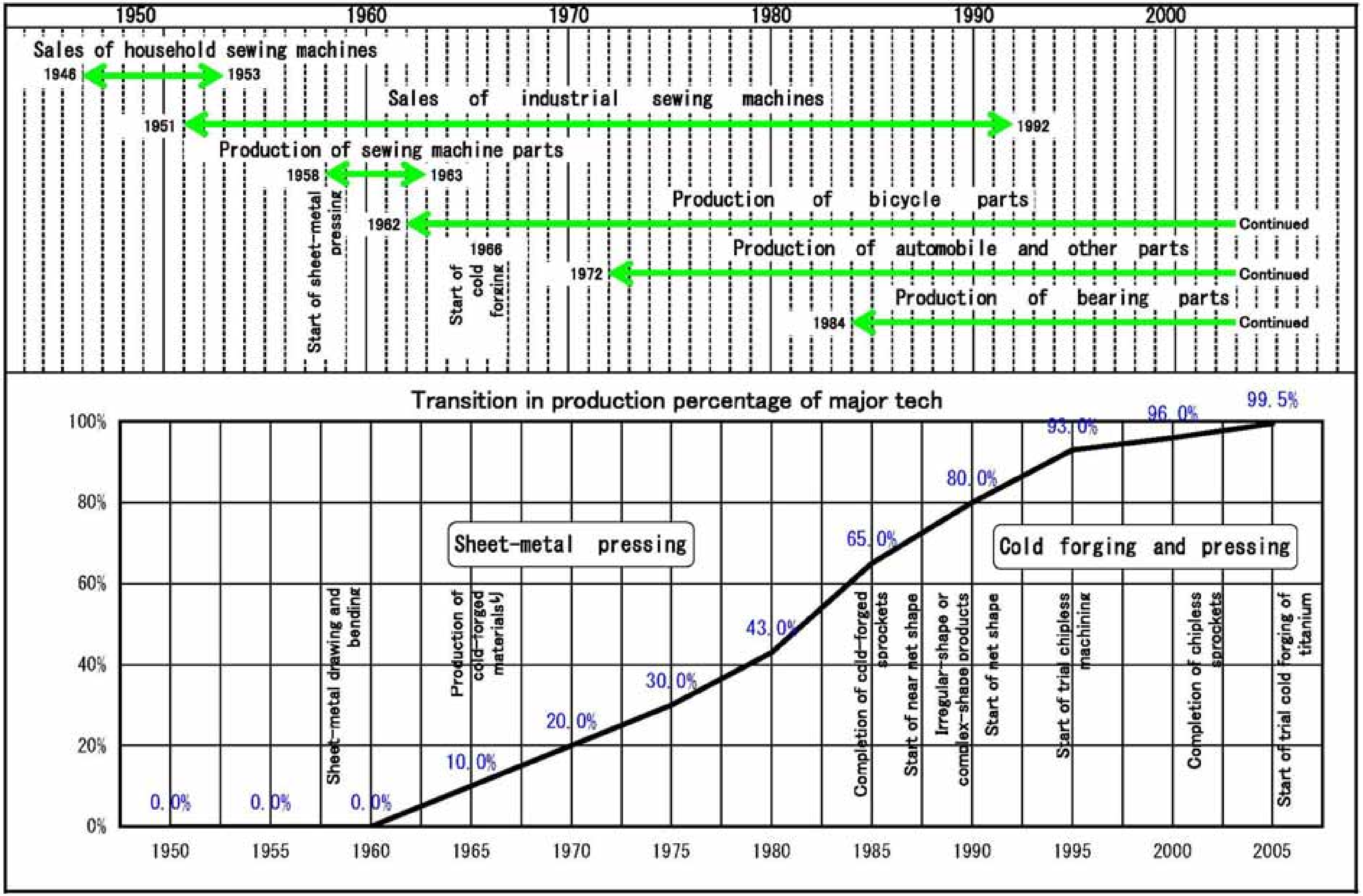
社　屋　全　景

工 場 内 設 備

Transition in sales items



1.2 What is high-carbon chromium bearing steel?

JIS G 4805 prescribes a fully hardened steel with a chemical composition of about 1-percent carbon and 1.5-percent chromium as high-carbon chromium bearing steel (SUJ).

SUJ stands for (S) steel, (U) use, and (J) journal.
This steel is a proven grade of steel since it has been used for more than half a century with little change in its basic composition.

For this special type of steel, JIS specifies the use of an electric furnace for manufacturing molten steel, meaning that killed steel is subjected to electric vacuum degassing treatment. This is done to uniformly distribute fine spherical chromium carbide in the structure.

SUJ 1 and 2 are used for small sizes of balls, rollers and races, and account for the most common usage of SUJ. SUJ 3 is used for medium sizes. For large sizes, SUJ 4 and 5 are used. Molybdenum is added to SUJ 4 and 5 for good hardenability. This ensures appropriate use.[2)3)4)]

2. Process of cold forging of SUJ 2 materials from trial fabrication to automated production

2.1 First stage (1984 to 1986, start-up period)

In 1981, our company was using the SAE 5120 material as the blank to fabricate bearing inner races as a pipe-shaped product through the following processes:

Bar material → Saw cutting → HAS (heat annealing spheroidizing) → B (lubricating surface treatment: metal stearate soap coating over zinc phosphate conversion coating, commonly called bonderite bondalube) → CF (cold forging) → P (piercing)

In 1984, bearing races were made using a SUJ 2 material as the blank. The cutting blank was generally made from a bar material by hot forging with a large draft on the inner bore. The cutting process proceeded from rough finishing → semi-finishing → finishing, but the yield was poor.

In 1984, customers requested an improved yield by CF, a substantial reduction in the subsequent cutting process, shortened lead time, and improved productivity.

We searched related literature, surveyed the trade, and attended academic meetings regarding cold forging of an inner race with a bottom using SUJ 2. However, we were unable to find any clues to the mass production of SUJ 2. Thus, we had no choice but to try CF by putting a SUJ 2 material in the die, which had been used to form the SAE 5120 material. After several cycles, the result was buckling of the counter punch, breakage of the upper punch at the base, large variance in bottom thickness, and poor roundness of the product, thus revealing the poor workability of SUJ 2 and making an ineffectual start.

Up until 1986, trial and error was repeated concerning die material (heat treatment, hardness,shape, dimensions) and blank shape (weight control). As a result, the die life was graduallyprolonged and it became possible to forecast production (Table 1 and Figure 1).

1) Product 1 (Photograph 1)

Product 1

Product 2

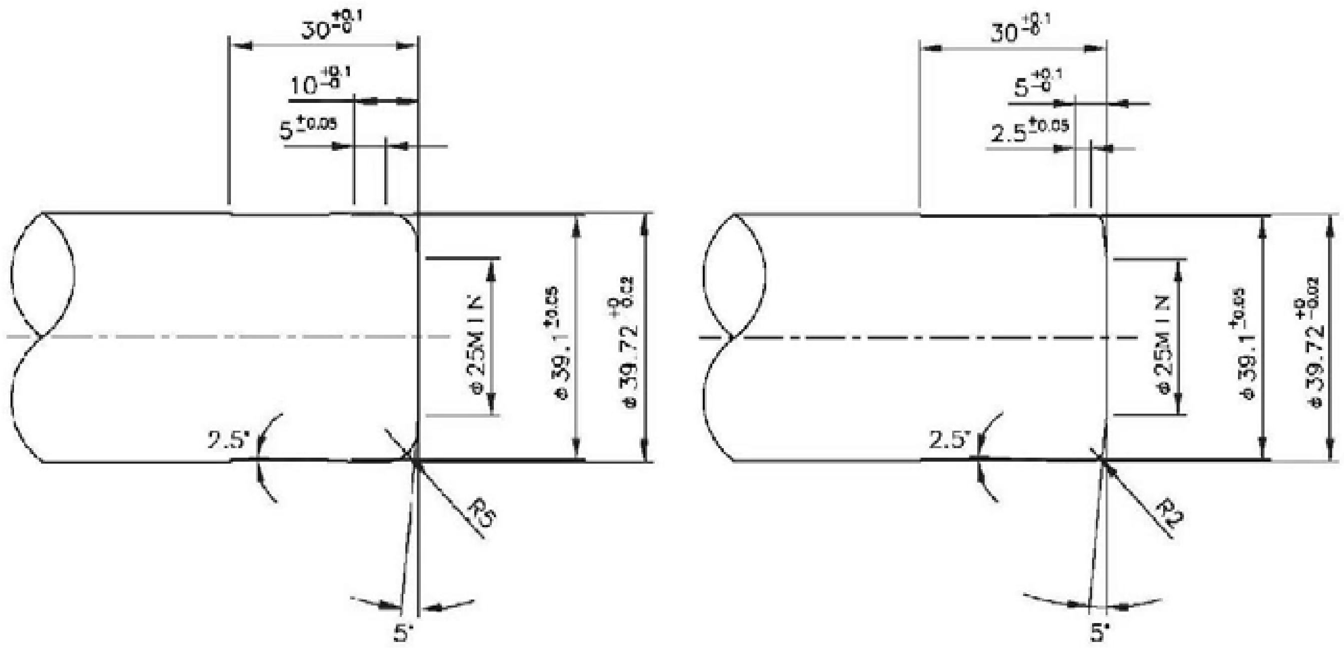
OD ϕ56.38 ID ϕ39.72H6.1

Photograph 1. Introduction of bearing inner race

(1984 to 2006)

Table 1. Improvement of upper punch material and hardness

	Before improvement	After improvement
Material	SKH-9	SKH-55
Hardness	60~61 HRC	64~65 HRC



Before improvement After improvement

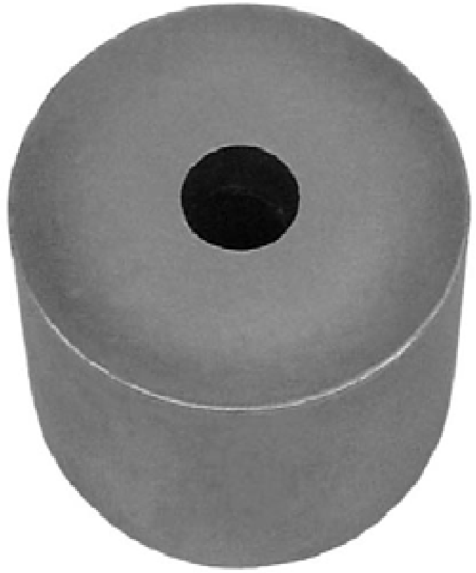
Figure 1. Improvement of upper punch land shape

2.2 Second stage (1986 to 1996, production increase and improvement period)

1)Manufacturing process of Product 3 (Photograph 2)

Top face

OD ϕ40.3 ID ϕ27



Rear face

H32.1 P:OD ϕ5 T9

Photograph 2. Product 3 (1987 to 2008)

(1) Selection of manufacturing process

In giving priority to yield, eccentricity and die life, we chose manufacturing process 1 (Figure 2). (In manufacturing process 2 shown in Figure 3, the swaging process may be omitted if the yield effect is not expected or accuracy of the swaged outer diameter is not required.)

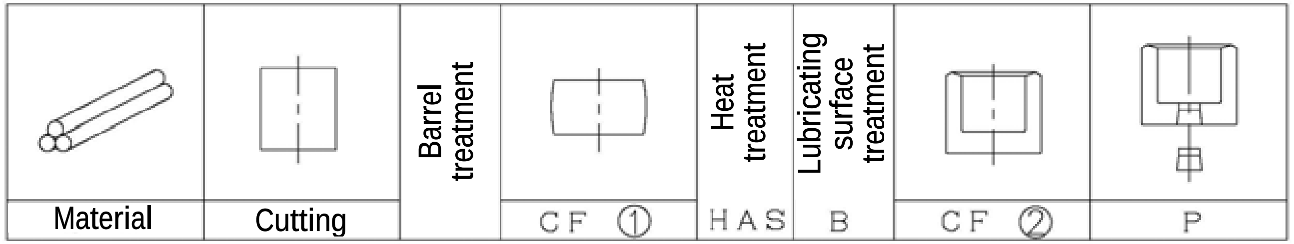


Figure 2. Manufacturing process 1

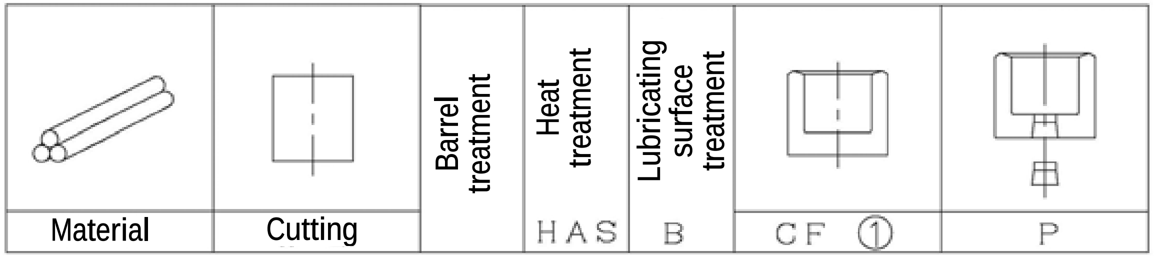


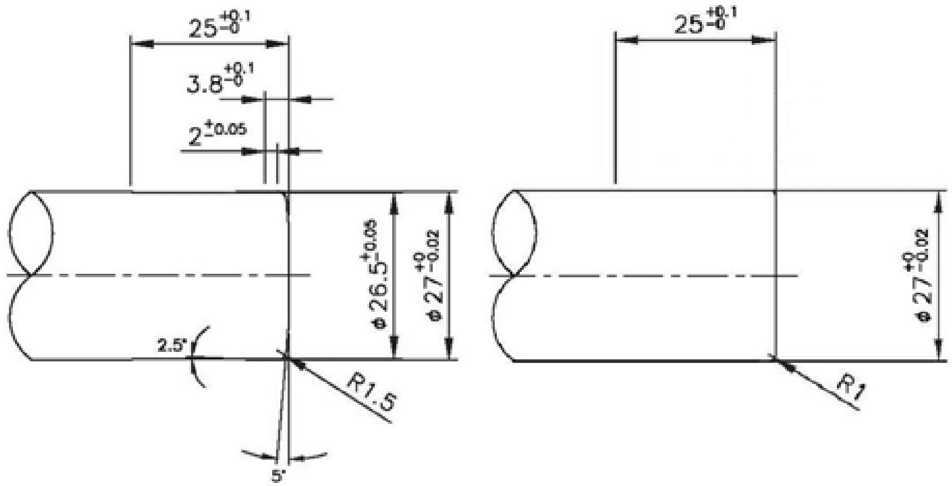
Figure 3. Manufacturing process 2

(2) Improved accuracy of CF products

①Flattening the bottom angle

②Reducing the inner bottom corner radius

③Stabilizing the entire length and shape of CF products To push the top face of the product, the upper punch tip was made straight (Figures 4 and 5).



Before improvement After improvement

Figure 4. Improvement of upper punch shape

④ Reducing eccentricity
(0.2 mm → 0.03 mm)

(A) Blank weight control

(B) Outer diameter and thickness accuracy control of CF ① swaging

(C) Preparation of the die and press so that the punch falls perpendicular to the die

⑤ Improvement of secondary fracture surface of P

(A) Changing the punch tip shape

(B) Reviewing the drawing clearance

(C) Adding a drawing back pressure

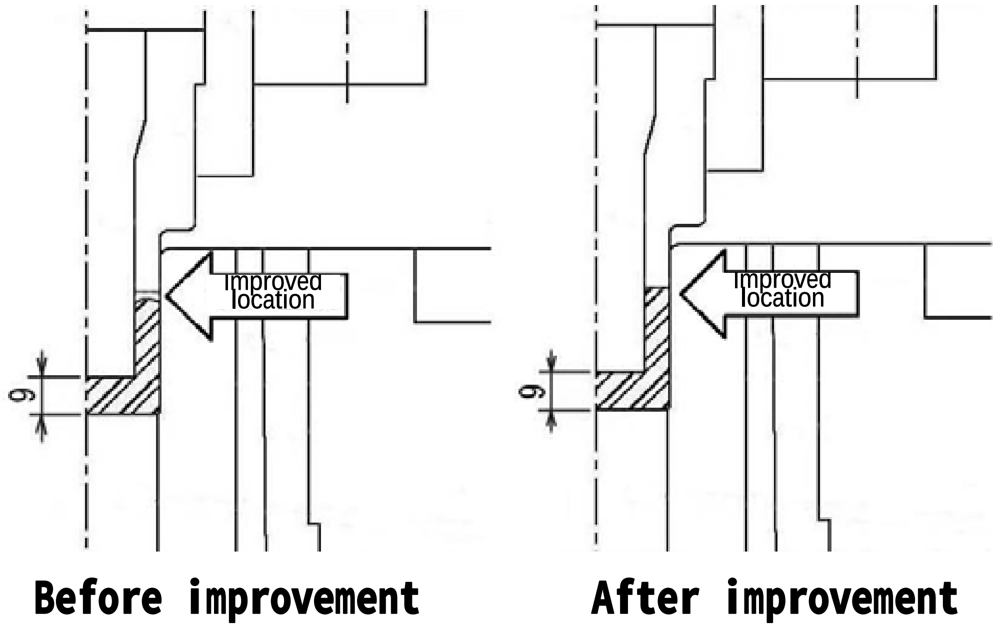


Figure 5. Improvement of working method

(3) Change in die life by heat treatment of die

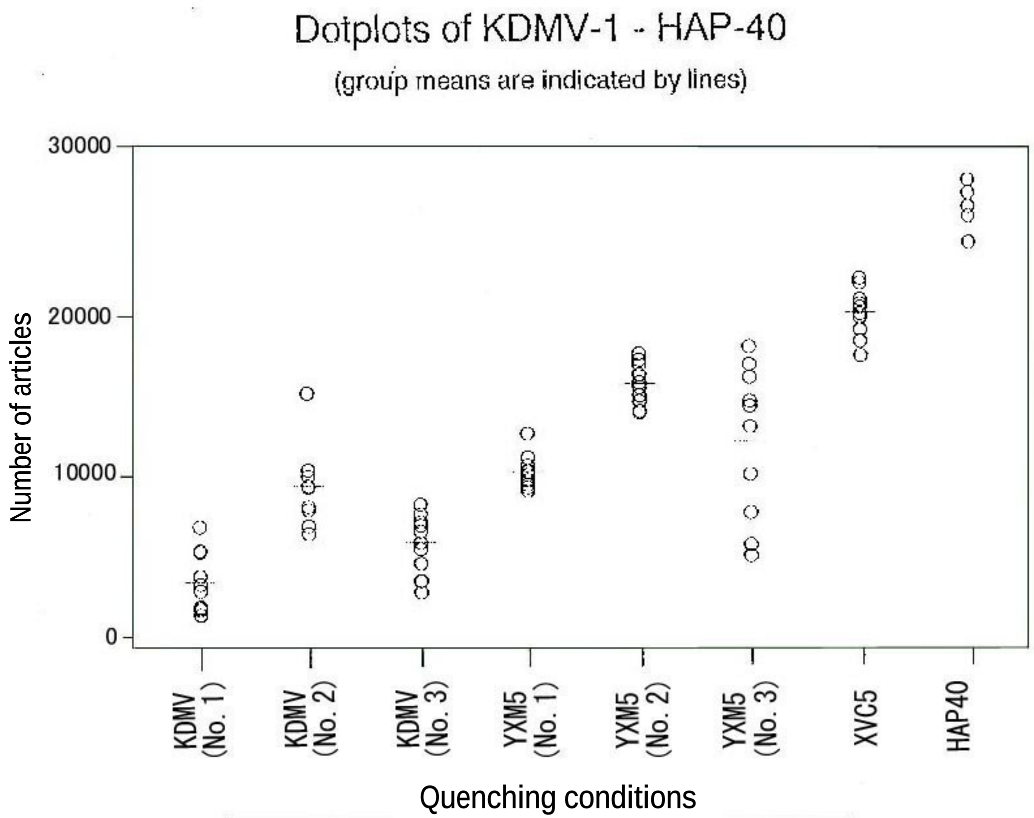
Because the punch is exposed to high pressure, its life as a tool is shortened by breaking, buckling, cracking, chipping, scuffing and abrasion.

After trial and error was done to achieve such conflicting requirements as high rigidity, high toughness and high abrasion resistance (Table 2), a compromise was reached. Figure 6 shows the upper punch life upon said compromise.[5)]

Table 2. Quench hardness by materials

Type	JIS	Daido	Hitachi	Koshuha	Standard working hardness by JIS (HRC)	Standard working hardness at Hitachi (HRC)	Standard working hardness at our company (HRC)
Molybdenum-based, high-speed steel	SKH55	MH55	YXM5	HM35	64 or more	62~66	64~65
	SKH57	MH57	XVC5	MV10	66 or more	63~67	65~67
Matrix high-speed steel	—	MH85	YXR3	KDMV	—	58~61	61~62
Powder high-speed steel	—	DEX40	HAP40	—	—	64~67	64~66

* Tempered three times



Material	No.	Quench hardness (HRC)
KDMV	1	59～60
	2	61～62
	3	62～63
YXM5	1	63～64
	2	64～65
	3	65～66
XVC5	—	65～67
HAP40	—	63～64

Figure 6. Upper punch life

① **Improving the upper punch abrasion resistance**

The upper punch was subjected to various kinds of surface treatment. As a result, TiC was deemed most suitable for SUJ 2, that is, no scuffing occurred and the abrasion limit was extended (Figure 7). (The CF product inner dimensions were controlled at ±0.02 mm.)

② **Improving the die abrasion resistance**

The die material was changed to cemented carbide (G3). As a result, the die life was extended from 0.1 million to 1.3 million cycles. (The CF product outer dimensional accuracy was controlled to within ±0.02.)

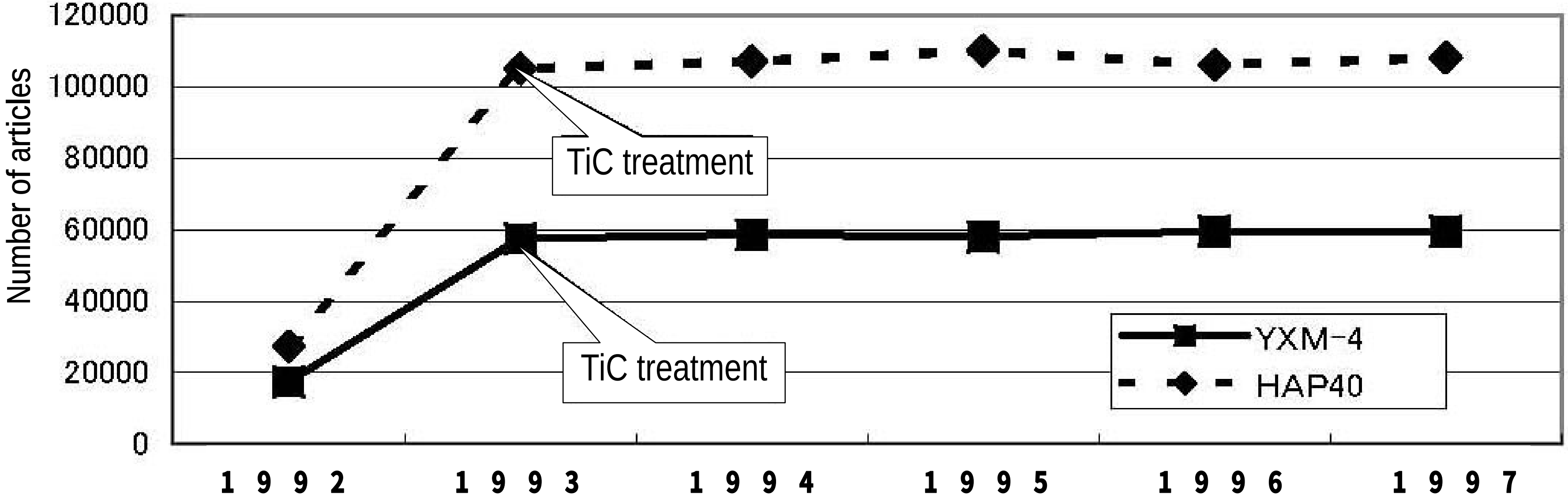
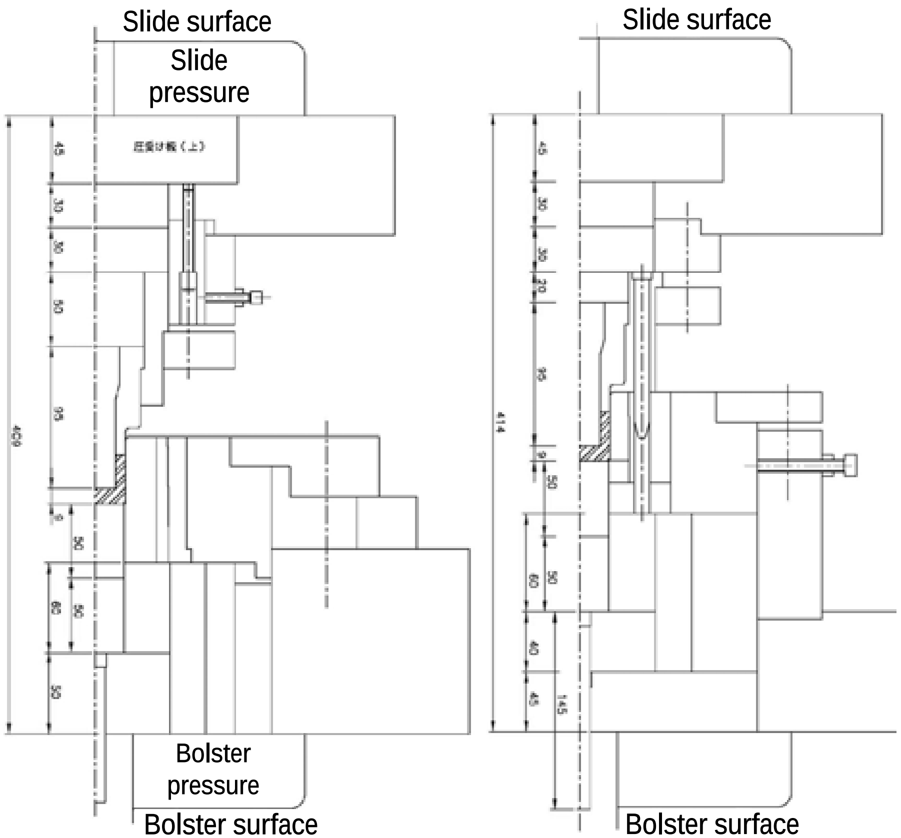


Figure 7. Change in upper punch life

(4) Shortening the die change time and improving CF productivity

The die assembly was changed from the upper die adjusting type to the lower die adjusting type (Figure 8). As a result, the die setting time was shortened and productivity was improved.



Before improvement (upper die adjusting type) **After improvement** (lower die adjusting type)

Figure 8. Die assembly drawing

(5) Stabilizing quality and shortening the measuring time

By ameliorating and improving the inner/outer run-out measuring jigs and dimension measuring jig for inspection use, the incidence of nonconforming articles due to inspection mistakes was reduced. The quality was stabilized and inspection time shortened.

(6) Rationalization by improving HAS of blank SUJ 2

The blank heat treatment process was improved. The HAS hardness, which was around 93 HRB before improvement, was stably reduced to 84 to 86 HRB after improvement. The carbides were finely spheroidized and distributed uniformly (Figure 9). (The JIS provision for HAS hardness of SUJ 2 is 94 HRB or less.)

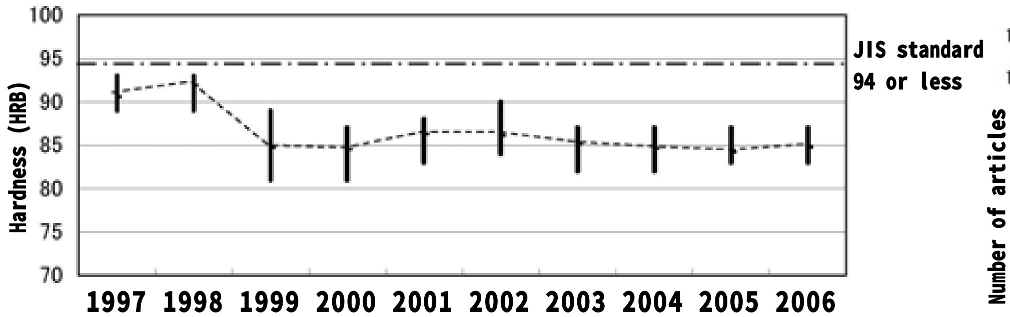


Figure 9. Change in HAS hardness

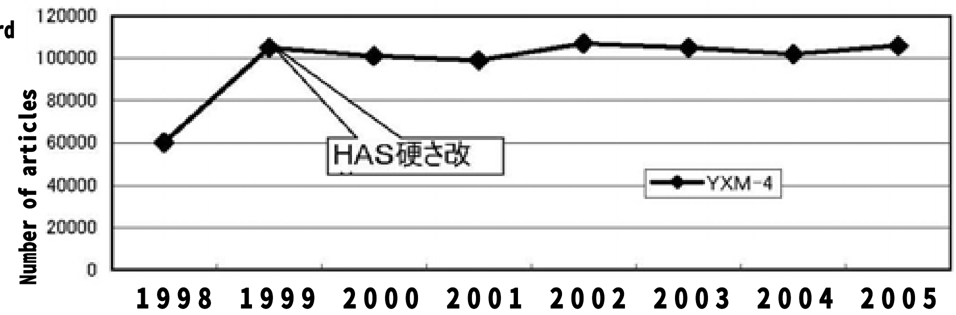
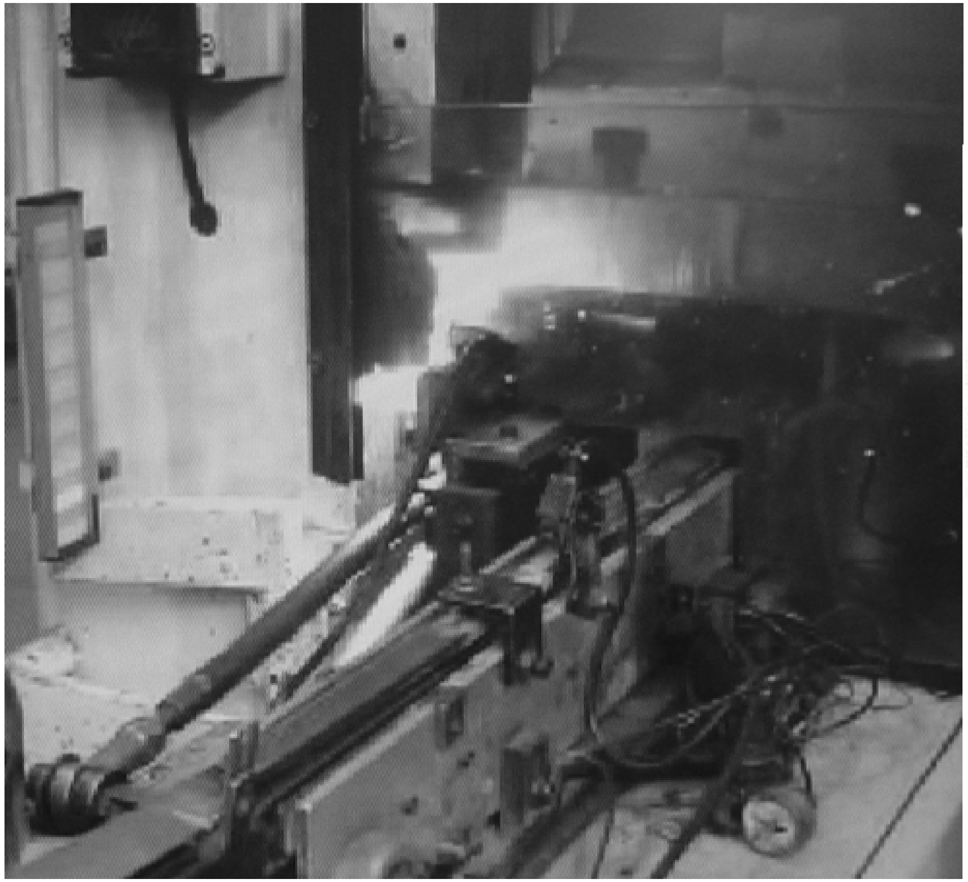


Figure 10. Upper punch life

(7) Automation

These ameliorations and improvements made field manufacturing automation possible (Photograph 3) and improved productivity (Figure 11).



Photograph 3. Automation

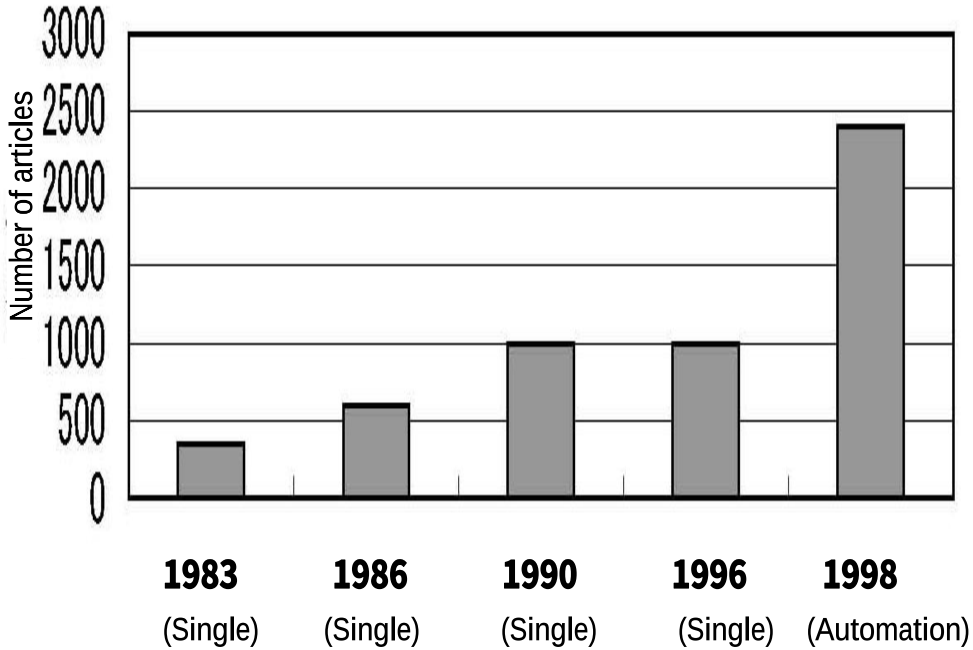


Figure 11. Change in productivity (per hour)

3.1 Thin-walled product

When a thin-walled product is quenched after machining, there is a high incidence of quench bending, resulting in a high percentage of defective products. By making the residual stress distribution as uniform as possible during the CF working, quench bending can be conversely reduced.

In terms of shape, the fine details of the die can be transferred to the product. By using this advantage, subsequent working can be substantially reduced. One problem with CF working was that lubricating surface treatment with conventional B resulted in poor slippage. Therefore, the material fluidity is poor and the dimensional target can hardly be attained. The transfer performance consequently becomes poor. As a countermeasure, B was changed to BM (coating of a mixture of graphite and molybdenum disulfide (MoS_2)[i] over zinc phosphate conversion coating). (The popular name BMS refers to Bonderite MoS_2.) Care must be taken because BM is more sensitive to moisture than B and the duration of effect is short compared to B.

One advantage of the chip-less working of CF is that the CF finished skin can be used as is. For this purpose, the surface finish conditions of the die and the lubricating surface treatment conditions of the blank are important factors.

Examples of thin-walled products of SUJ 2 material (Photographs 4 and 5).

Blank 3.3-mm thick → CF1 process → Finished product

Photograph 4. Product 4 (1996 to 2008)

Blank 3.3-mm thick → CF1 process

Photograph 5. Product 5 (1998 to 1999)

1)Manufacturing process of Product 5(Figures 12 and 13)

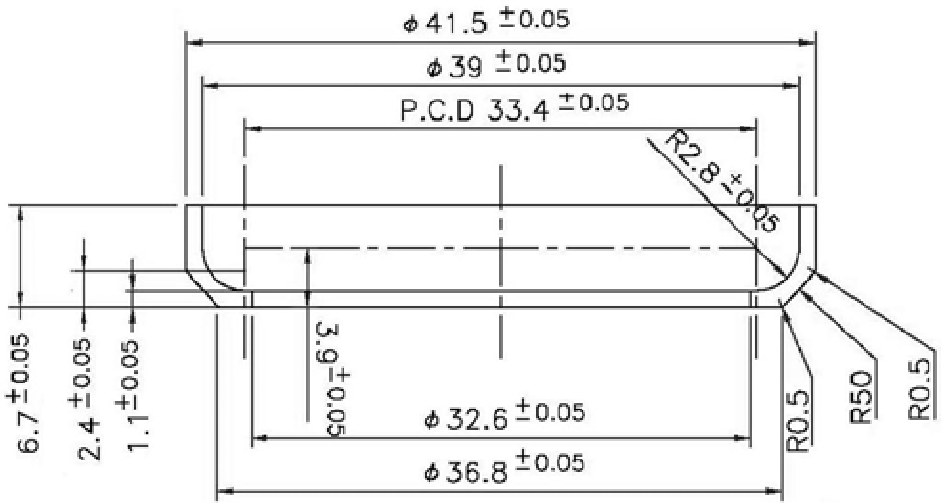


Figure 12. Drawing of CF of Product 5

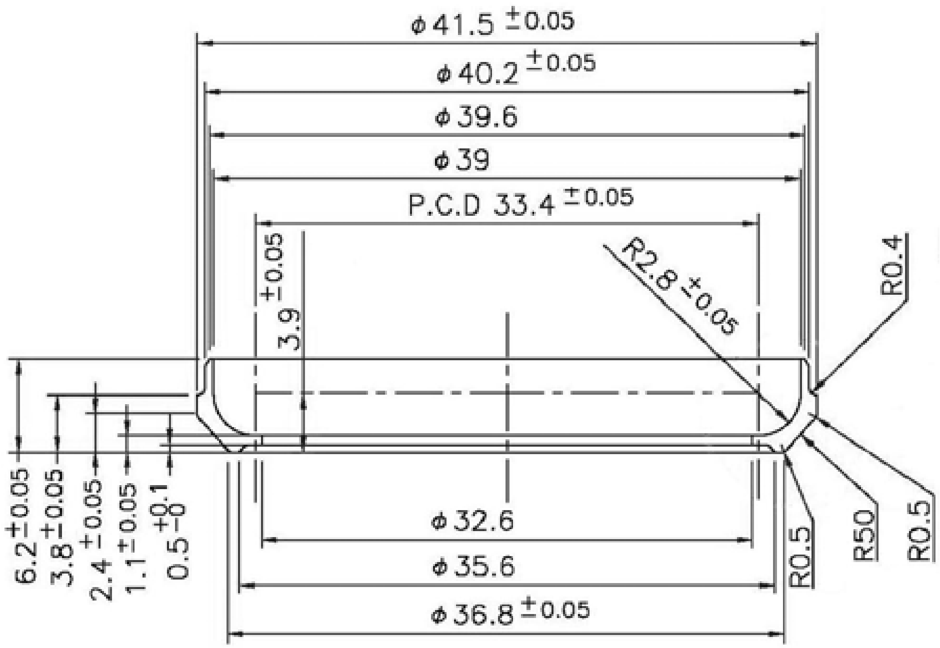


Figure 13. Product 5 in finished state

(1) Change of manufacturing process

With manufacturing process table ① (cutting only) shown in Figure 14, the quench bending was large and the percentage of defectives abnormally high.

With manufacturing process table ② (CF + Cutting of end face only), there was little quench bending and the desirable results were obtained.

As a cause for such little quench bending, the residual stress might be made uniform by CF working.

Regarding the accuracy per ball, that is, both roundness (Figure 16) and surface roughness (Figure 17), the desirable results were obtained and the limit of thin wall working of SUJ material was extended.

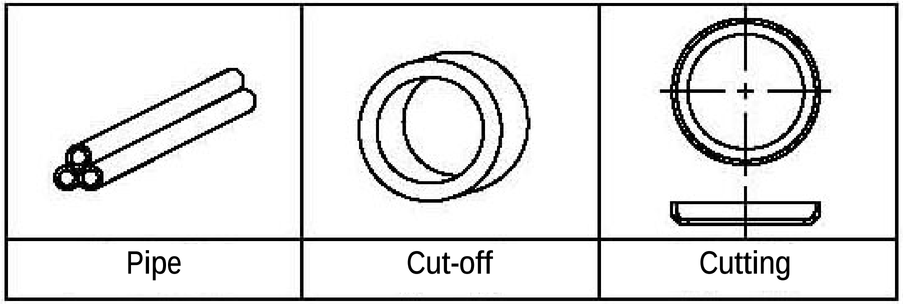


Figure 14.
Manufacturing process table ① (cutting only)

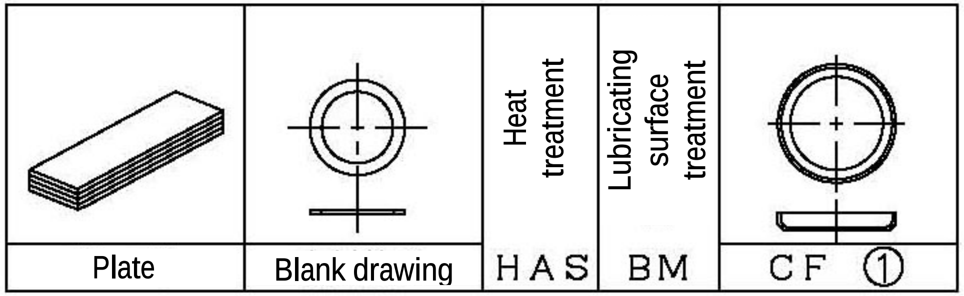
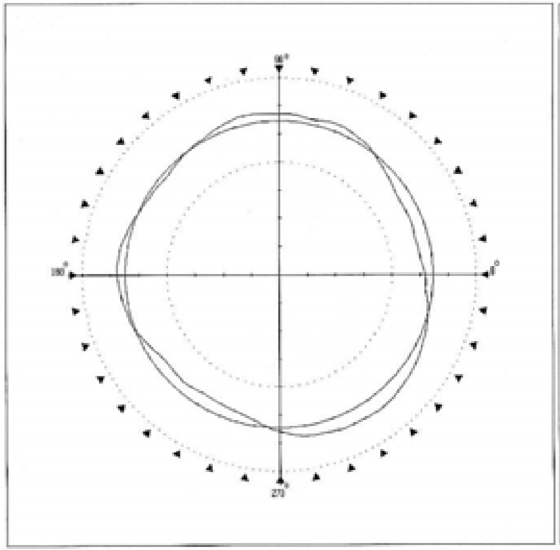


Figure 15. Manufacturing process table ②
(CF + Cutting of end face only)

After CF

LS roundness results	○ 4.95 um	Scale 5.00 um	Filter 1-15 upr
Feature name DFAULT	4.10 um	Z-height 6.0 um	Shape 100.0 %
Measurement number 00	∠ 340.6 deg	Datum:Spindle	Measurement mode
R 86.799 um	10.75 um	Filter type 2CR	Date of measurement 15-05-2006



After quenching

LS roundness results	○ 7.35 um	Scale 5.00 um	Filter 1-15 upr
Feature name DFAULT	1.95 um	Z-height 5.6 um	Shape 100.0 %
Measurement number 01	∠ 332.5 deg	Datum:Spindle	Measurement mode
R 86.585 um	8.90 um	Filter type 2CR	Date of measurement 15-05-2006

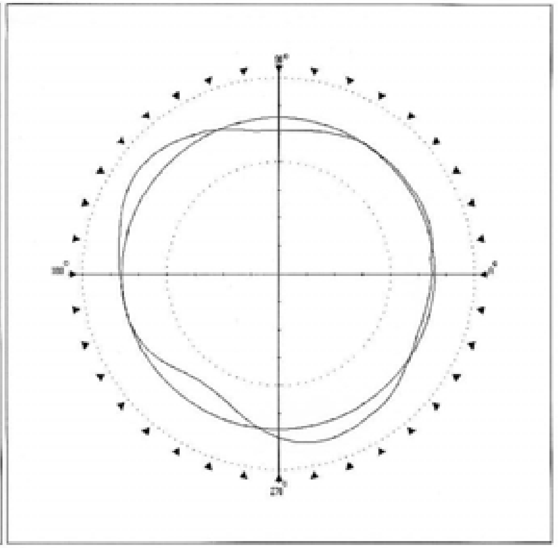
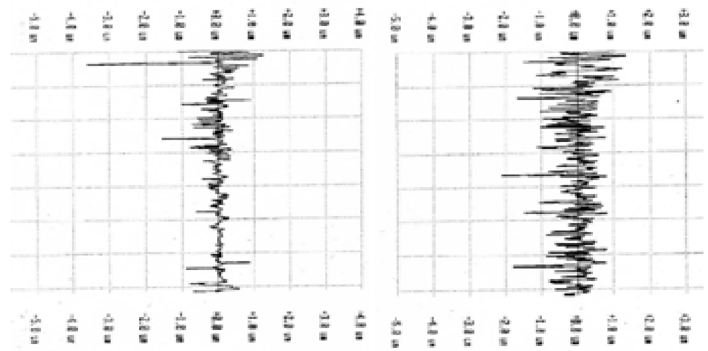


Figure 16. Roundness data

Horizontal scale: 500.000 per one division
Horizontal magnification: × 20.0–
Vertical scale: 500.000 per one division
Vertical magnification: × 20.0–
Shape start point: 0.256 mm
Shape end point: 3.833 mm
Note: All shape data are not printed out.

Horizontal scale: 500.000 per one division
Horizontal magnification: × 20.0–
Vertical scale: 500.000 per one division
Vertical magnification: × 20.0–
Shape start point: 0.482 mm
Shape end point: 4.084 mm
Note: All shape data are not printed out.



LS Rad 2.76612mm Pich 2.817mm
DX_datum 2.077mm, X_datum 0.000um
DZ_datum 1.902mm Z_datum 0.000um

Ra 0.1773 um Rt 4.9609 um
Ru 4.9609 um RzJIS 0.8353 um

LS Rad 2.777513mm Pich 3.203mm
DX_datum 2.302mm, X_datum 0.000um
DZ_datum 2.227mm Z_datum 0.000um

Ra 0.3517 um Rt 3.4727 um
Ru 3.1130 um RzJIS 1.2837 um

Figure 17. Surface roughness data

3.2 Products of deformed or complex shape

The surface finish of the CF die must be fine in order to use a product having an oval or irregular inner shape as a commercial product without further processing. Not only that, the die assembly should become complex for easy control and maintenance of the corner radius of the upper/lower dies and punches.

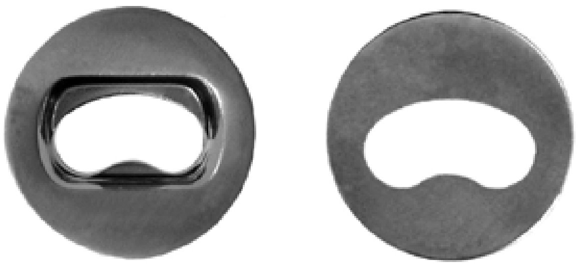
It is desirable to improve the accuracy of the fracture surface by the last process of T (trimming) or P. In T, the drawing burr allowance must be as thin as possible or continuously reduced. In P, the CF worked surface must remain as much as possible. To avoid primary and secondary sheared surfaces, and make a beautiful skin, contrivances are required of the corner radius and clearance of the drawing tool, holding down of the blank,

Examples of deformed or complex shape products of SUJ 2 in Products 6 to 13 (Photograph 6 to 11)

Top face　　Cut surface
Product 6　OD ϕ29H30

Top face　　Cut surface
Product 7　OD ϕ24.3 H24

Photograph 6. (1999 to 2008, SUJ 2)



Top face　　Rear face
Photograph 7. Product 8
(1999 to 2008, SAE 5120)

Top face　　Cut surface
Photograph 8. Product 9
(2003, Completed trial production of SUJ 2)

(Products 8 and 9: OD 27.9 mm, H 30 mm, same size)

Blank 4.3-mm thick → Product → Scrap

Photograph 9. Product 10 (2003 to 2008, SCM 415)

Blank 4.5-mm thick → Product → Scrap

Photograph 10. Product 11

(2003, Completed trial production of SUJ 2)

(Products 11 and 12 are the same size.)

Viewed obliquely from above　Cut surface　　Cut surface

Product 12　　　　Product 13

(2005 to 2008,SAE 5120)　(2006, Completed trial production of SUJ 2)

Photograph 11. (Products 12 and 13: OD 38.55 mm, H 37 mm, same size)

4.Future tasks for CF

Our company fabricates thin, long, small, deformed and complex shape articles, and gears and sprockets by cold forging on a net shape or chipless basis. The materials include SC material, alloy steel, aluminum and duralumin. In the bearing industry, cutting and grinding have long been done on proven manufacturing lines. Consequently, the competition was so severe that the workload is measured in units of seconds. Improving yield or reducing the cutting process alone cannot solve the problem. The advent of breakthrough technology is being awaited, and such technology will be achieved by a joint project that includes the blank, CF, cutting, lubricating surface treatment and heat treatment.

Given the globalization of the manufacturing industry, the shift of mass production overseas is naturally proceeding. To enhance the advantage of domestic production, high-grade products must be produced with high accuracy and high quality by multi-product, small-lot production. The necessary technology must be easy to transfer and completed as early as possible. Improving shop productivity is yet another task.

When considering the distance from the blank to end product, CF working time can be shortened compared to cutting, grinding and buffing, depending on how CF is done. With CF, uniform and stable accuracy can be obtained, and surface roughness controlled. Thus, this process can be considered a promising working technology having high potential for a breakthrough.

Therefore, three-dimensional simulation analysis, tribology (analysis of the mechanism of the contact part between the die and workpiece) and CF working after heat treatment are important but remain lacking. Thus, we should challenge these technologies. Moreover, a technology we have cultivated for many years is available to control the material flow during working. The ultimate concept of CF is “feel what the pressed material feels.” Taking this as the basic stance, we should attain high quality, high speed and low cost, which will become increasingly required from this point on.

In the field of CF manufacturing, staff should be trained in and master higher production technology. At the same time, it is also important to foster skills, sense and feeling gained from experience, then brush up and hand them over.

Finally, Photograph 12 shows some new and old products that we have fabricated.

Photograph 12. Some new and old products

5.Conclusion

The author, together with our staff, sincerely thank professor Takashi Ishikawa (of Nagoya University) for giving us this opportunity, Mr. Shuzo Matsumoto (former senior executive director at Shimano, Inc. and former manager of Shimano Laboratory) for rearing us in a strict manner regarding forging, Mr. Kazuo Shima (former executive director at former Koyo Seiko and former board chairman at DAIBEA Co., Ltd.) for giving us the opportunity to encounter SUJ 2, and our customers for always giving us subjects.

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ご清聴ありがとうございました。

２００８年　６月２０日

株 式 会 社 タ イ シ ョ ー テ ク ノ

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