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DIE TECHNOLOGY FOR PRECISION FORGING

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Summary

The characteristic feature of tool materials for precision forging is reviewed first, and then the results of the recent development of tool material are introduced. The high speed steel, PM (powder metallurgy) high speed steel, tool steels and cemented carbide are explained. As an example of forging technology in NICHIDAI, die structure and optimization for tool life of scroll part in forging is presented. To solve the problem in die life, heat treatment condition is changed to result fine martensite after oil quenching, and Charpy impact value is extended.

1. Introduction

Manufacturing of forging products with high accuracy is strongly demanded by the automotive industry. It is important to improve the tool life for total cost reduction in forging. Precision forging has a purpose of reducing or eliminating subsequent machining operation. But due to the high tool pressure and friction, forging tool tends to fail by low cycle fatigue or wear.

Precision forging tools require optimization of the tool performance through designing the forging process. Recently, marked advances in the development of FEM simulation have been made, and it is effectively applied in designing of forging process to improve the tool life.

In this paper, tool materials for precision forging are reviewed first, and then a case study of improving the fatigue life of a scroll-shaped tool is introduced.

2. Precision forging tool

2.1 Forging tool material

The tool pressure in precision forging is usually quite high; the maximum forming pressure reaches about 2,000 ～ 3,000MPa. Further, various stress modes such as tension, compression and bending occur. Due to the high pressure and local tensile stress in precision forging, most of the tools fail by low cycle fatigue. The optimum design of precision forging tool requires the knowledge of the stress state and tool material.

The demand to the tool steels becomes more and more severe. Recently, many tool steels for precision forging such as matrix type high speed steels and high speed steels produced by powder metallurgy were developed.

2.2 Tool steels

Table1 shows the chemical compositions of tool steels. To improve the hardness of the carbide in tool steel, Cr, Mo, V and W are added to high carbon steel. The hardness values of various carbides and matrix are shown in **Fig.1**, in which "M" means the added metal for hardening.

Table.1 Chemical composition of tool steels (mass%).

	JIS	C	Si	Mn	Cr	W	MO	V
Cold Work Die Steel	SKD11	1.5	0.3	0.4	12.0		1.0	0.3
High Speed Steel	SKH51	0.85	0.3	0.3	4.2	6.5	5.3	2.1
PM High Speed Steel	SKH40	1.28			4.15		5	
Hot-Work Tool Steel	SKD61	0.4	1	0.4	5.2		1.3	0.9

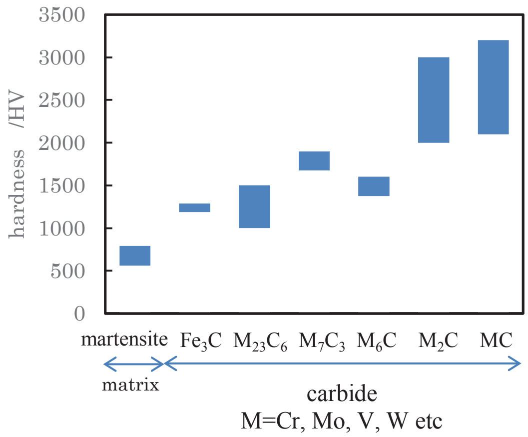


Fig.1 Carbide hardness[1]

Carbide increases the hardness but decreases the toughness. To generate fine carbides, the cold work die steel SKD11 is added by V. **Fig.2** shows tempering curves for SKD11 and high speed steels. The tempering temperature is chosen to get optimum balance of hardness and toughness. In order to improve the toughness, tool steel based on SKD11 is developed[2]. Due to the low C and low Cr, the carbide is improved. Secondary hardening in tempering at around 550℃ increases the hardness as shown in Fig.2[1].

High speed steel SKH51 is generally used for cold forging. To strengthen the carbide in high speed steel, Cr, W and Mo are added. The high hardness of high speed steel SKH51 is attained by secondary hardening in high temperature tempering at 550℃.

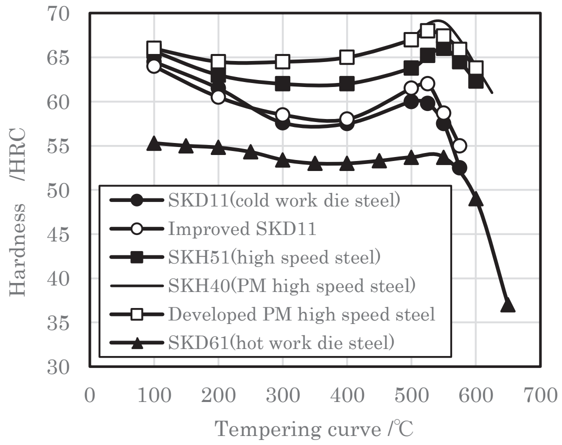


Fig.2 Tempering curve[1]

Both SKD11 and SKH51 contain a large amount of carbide. It is reported that the crack initiating site of fatigue fracture is carbide and that toughness decreases with increasing volume and size of carbide particles[3]. To improve the tool life, tool material companies developed steels having higher fatigue strength, toughness and machinability compared with conventional tool steels by changing the carbide morphology.

PM (powder metallurgy) high speed steel with fine carbide has higher wear resistance than high speed steel. Recently, some matrix-type high speed steels which have less carbon content to improve ductility and high temperature strength have been developed by some Japanese companies. The matrix-type high speed steel provides high fatigue strength, higher toughness and hardness at high temperature and machinability[4] -[8].

2.3 Cemented carbide[9]

WC-Co type cemented carbide alloy is often used for cold forging tools because of the high hardness, large Young's modulus, low thermal expansion and high heat conductivity and high strength in compression. Carbide material of WC-15～27mass%Co are used for cold forging. Although the carbide tools can endure a high compressive pressure, they are easily fractured in tension. The hardness of cemented carbide increases as the grain size of WC decreases and the amount of Co% decreases. The fracture toughness of cemented carbide increases as the grain size and Co mass% increase.

2.4 Comparison of tool materials

Fig.3 shows relationship between hardness and toughness of the tool materials. The tool steels developed by material companies in Japan are shown in **Table2**. SKD11 and SKH51 are widely used as tool steels for cold forging. On the other hand, PM high speed steel, matrix high speed steels and WC alloy are used in dies subjected to high static and impact load

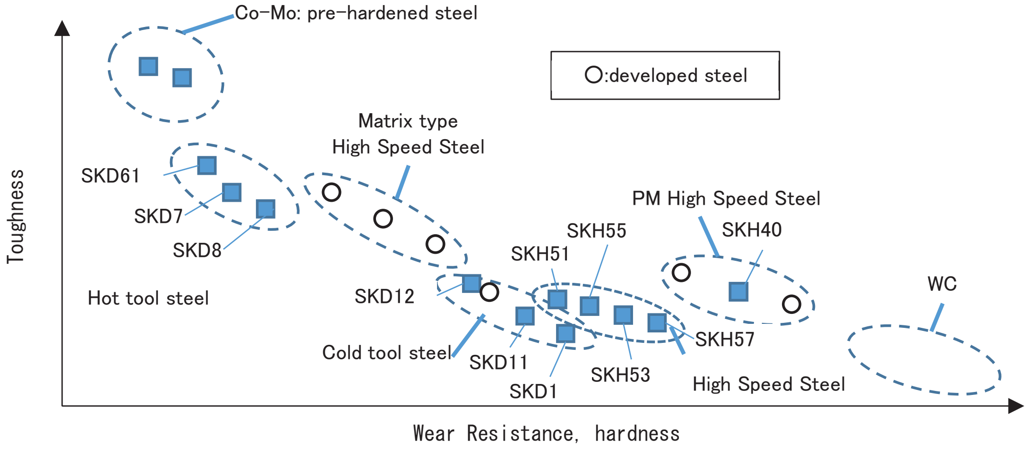


Fig.3 Relationship between hardness and toughness of tool steel[10]

Table2 Tool steel of material company in Japan[10]

	JIS	Aichi steel	Sanyo Special Steel	daido steel	Nippon Koshuha Steel	Hitachi Metals	NACHI-FUJIKOSHI
Cold Work Die Steel	SKD11	SKD11	QC11	DC11	KD11	SLD	CDS11
	SKD11 (develop)	AUD15	QCM8	DC53	KD11S KD21	SLD8	MDS9
High Speed Steel	SKH51		QH51	MH51		YXM1	SKH9
	Matrix type			DRM2 DRM3	KMX1 KMX2 KMX3	YXR33 YXR3 YXR7	MDS1 MDS3 MDS7 MATR1
Hot-Work Tool Steel	SKD61						
PM High Speed Steel	SKH40			DEX40		HAP40	FAX38

3. Example of precision forging

The forging technology of scroll parts used for air compressor is explained first, and then the structure of forging tool are introduced.

3.1 The forging technology for scroll parts[11]

The scroll parts used in an air conditioner, shown in **Fig. 4**, is of aluminum alloy with high silicon content and has a spiral fin on a round end plate. Due to this complex shape, scroll parts are usually made by casting with subsequent machining.

Fig.4 Extruded scrolls without and with counter force.

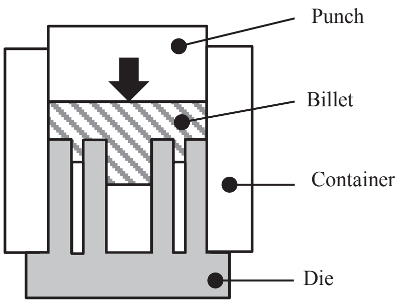
But due to the low yield ratio of the material and difficulty in machining of the aluminum alloy, manufacturing of scroll by metal forming was desired.

NICHIDAI started to develop the method of manufacturing scrolls by using forward extrusion with counter tool around 1993.

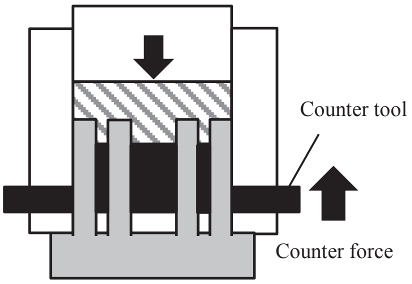
It was considered that if the long spiral fin could be extruded to a uniform length and the end surface is flattened, the material and machining costs are saved greatly.

When forward extrusion is carried out using a die with multiple exit holes, the lengths of the extruded parts are not equal as shown in **Fig. 5(a)**, and machining is necessary to equalize the lengths of the extruded parts.

If a billet is extruded against a floating counter tool supported by pressure as shown in **Fig. 5(b)**, it is possible to control the flowing out velocities to attain equal extruded lengths, and if a higher pressure is given to the floating tool, the extruded end surfaces become flat.



(a) Conventional



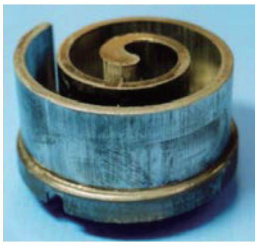
(b) Counter pressure

Fig.5 Explanation of extrusion against counter tool

Fig.6 shows the experimental results of forward extrusion of spiral fin (a) without and (b) with a floating counter tool supported by pressure.

It is found that the counter pressure, which is necessary to equalize the extruded lengths is about 3 % of the flow stress in the case of Fig. 6(b), but the extruded ends are not flattened with this low pressure. The lengths of the many small fins are equalized and the extruded ends are flattened.

(a) Without counter



(b) With counter force

Fig.6 Extruded scrolls without and with counter force.

3.2 Die structure for extrusion of scroll

Fig.7 shows the die structure for extruding a scroll against a knockout tool supported by a counter force.

The insert punch, the punch sleeve and the punch are pushed forward simultaneously to extrude the billet through an exit of spiral in shape. During extrusion, the knockout tool is pushed up by the KO pins with a constant force.

As extrusion proceeds, the knockout tool retreats downwards by giving a counter pressure to the extruded fin. All the tool segments are set in a die set as show **Fig.8**, and the die set is mounted on a 10,000 kN mechanical press, and the counter force is applied by a hydraulic cylinder.

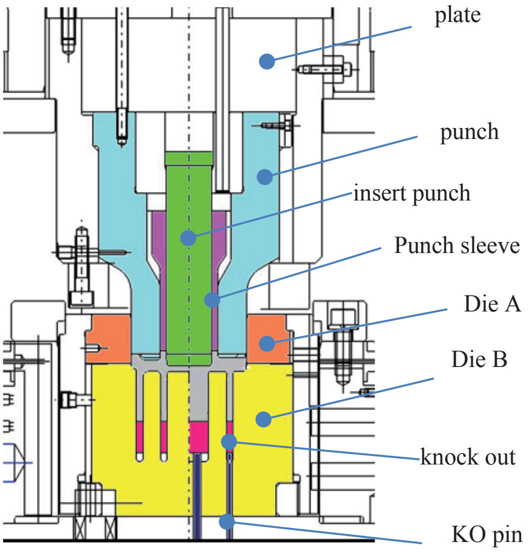
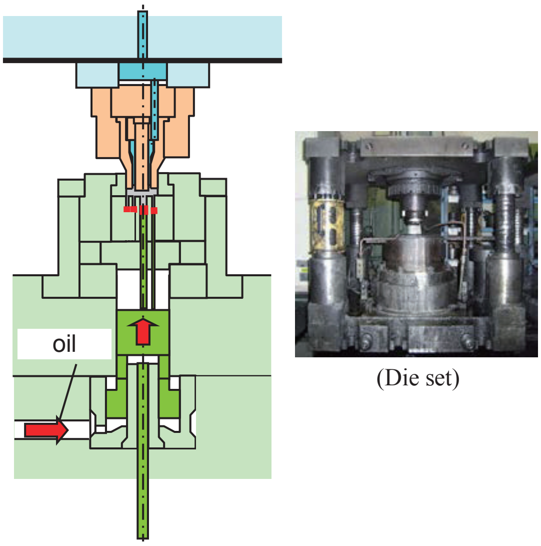


Fig.7 Die structure for extruding a scroll

Fig.9 shows products processes a scroll parts. The billet is a thick round plate cut out from a bar of continuously cast Al-(8–12 % Si) alloy. The billet is dipped into a graphite type lubricant and heated to around 420°C before being inserted into the die.



(Die set)

(Die set structure)

Fig.8 Die set structure for extruding a scroll

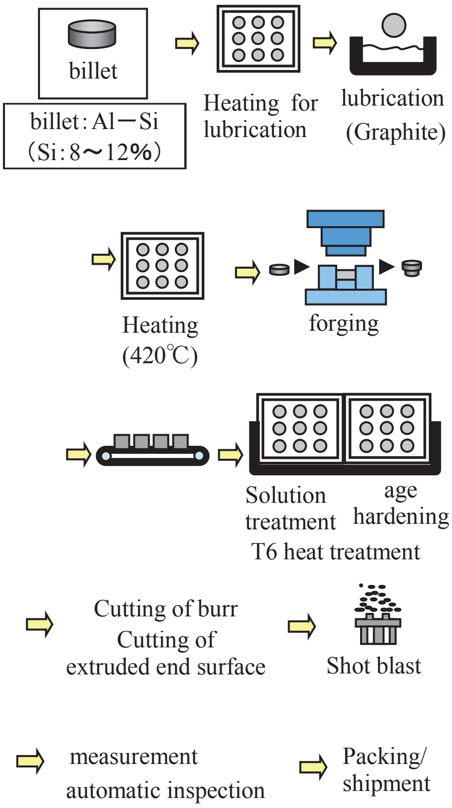


Fig.9 Products processes a scroll parts

3.3 Tool manufacturing processes

Tool manufacturing processes of Die B as show in Fig.7 is introduced. The material of die B is a matrix high speed steel.

3.3.1 Heat treatment

At first, residual stress is removed to reduce heat treatment distortion: i.e. the residual stress caused in rough cutting is removed by annealing. For heat treatment, the heating to 1130℃～1180℃, it is quenched and then tempered.

3.3.2 EDM and cutting

After heat treatment, the surface of the die is finished by grinding. The process of manufacturing of the spiral fin is as follows;

1) Rough shape is made by EDM(**Fig.10**)
2) Places with high dimensional accuracies are made by machining.
3) Surface of the spiral fin is finished by polishing. (**Fig.11**)

In tool manufacturing, EDM is carried out at first with a tungsten electrode in oil. In the early stage of surface finishing, polishing machine is used to remove of the tool mark in machining. In the later stage, polishing is carried out by human hand. The knockout hole is machined by wire EDM.

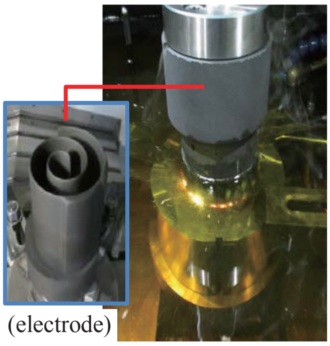


Fig.10 EDM of scroll fin


(By polishing machine) (By hand)

Fig.11 Polishing of surface

3.3.3 Improvement of tool life

During forging, fracture of the tool starts from the spiral fin surface after 30,000 shot.

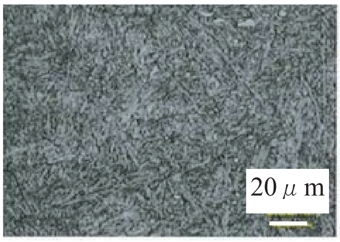
Problems encountered are follow.

1) Crystal grain coarsening
2) Grain-boundary carbide precipitation
3) Bainite formation

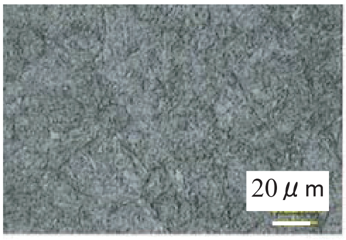
To solve those problem, heat treatment condition is changed.

1) Quenching temperatures is changed from 1145℃ to 1120℃
2) Holding time is changed from 42min to 32min
3) Cooling substance is changed from gas to oil.

The tool life was extended from 30,000 shots to 85,000 shots by changing the heat treatment condition. **Fig.12** shows the microstructure with different quenching conditions. Bainite is observed in the case of the gas quenching, fine martensite is seen after oil quenching. Charpy impact value shown in **Fig.13** could be extended from 50j/cm^2 to 200 j/cm^2 by changing the quenching conditions.



(a) Gas quenching



(b) Oil quenching

Fig.12 Microstructure

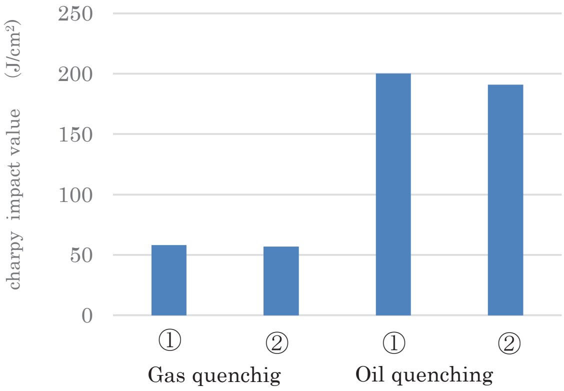


Fig.13 Charpy impact value

4. Conclusions

The characteristic feature of tool materials are reviewed first, and then the results of the developments of tool material for precision forging were introduced. It is explained that some tool steels for precision forging have been developed recently.

As a case study, it is introduced that the die life of scroll parts in forging was improved by changing the condition of heat treatment. The tool life was extended from 30,000 shots to 85,000 shots.

The developments of die technologies to reduce the manufacturing cost and to improve product quality are important to keep precision forging competitive against other manufacturing methods such as machining, casting and powder compaction.

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