Sumitomo's Steel Bars and Wire Rods for Automobile Industries

by
Kazuhiko Nishida / Dr. Eng., General Manager, Material for Automotive Use, Head Office
Atsushi Kido / Staff Manager, Bars & Wire Rods Technology Planning & Service Sec., Kokura Steel Works
Takeshi Sato / Assistant Manager, Bars & Wire Rods Technology Planning & Service Sec., Kokura Steel Works
Ryuji Koyama / Staff Engineer, Bars & Wire Rods Technology Planning & Service Sec., Kokura Steel Works

Synopsis

The purpose of this paper is to describe how Sumitomo has developed new products on the basis of customer needs. Automobiles should have not only function as a transportation device, but also protect human life, harmonize with society and perform responsibly for the environment. In order to fit these purposes, Sumitomo has been developing new products and also new technology such as no heat-treatment micro-alloyed steels and cold heading quality, boron-added steels and newly-developing combinations of material and process technology.

1. Sumitomo's Strategy to the Variation of Customer Needs

Sumitomo started producing steels for machine structural use in the 1960's when the automobile industry grew rapidly in Japan. At that time, the domestic annual capacity for producing automobiles increased by 500 000 a year, so the automotive industry desired that its operation should be efficient and steels also should show stable quality. Therefore, demand for high machinability resulted in development of several kinds of free-cutting steels such as sulfur, lead and calcium free-cutting steel. The amount of production of the free-cutting steels was increasing accompanied by automation of machining lines. On the other hand, steels suitable for cold heading were standardizing in conjunction with increasing application of cold heading for many parts.

As the number of automobiles increased rapidly in Japan, Japanese people became aware of the importance of harmonizing automobiles with society. Hence the acts concerning safety, exhaust gases or noise began to be effective and much more strictly up to date. To improve the gear's dimensional accuracy against noise originating from the drive line, the desire for tight control of chemical composition and hardenability tight control resulted in the need for less strain steel.

In order to satisfy these needs, Sumitomo Metals developed many technologies listed below: vacuum arc degasser (VAD), large section continuous bloom caster, wire rod mill with stelmor cooling device, block mill, horizontal-vertical rolling, bar mill equipped with no-tension-control, super finishing mill (SFM), and bar-in-coil device. Also both rolling mills were equipped with on-line hot eddy current testers. With all this, Sumitomo Metals was able to produce the bars and wire rods which showed not only excellent surface quality but also homogeneous chemical composition and thus hardenability.

2. Trend of Needs

The domestic automobile industry has been affected enormously during its developing stages by the factors listed below.

First, harmonization of the automobile and society such as safety, exhausted gases and noise, resulted from rapid domestic motorization. Second, resource and energy saving which began during the energy crisis. Third, international competitiveness under the appreciation of the Japanese Yen and also one-way globalization, that is hollowing out of economy. Finally, environmental issues, such as recycling of waste, which has caused the industry to handle more strictly than ever.

As a result, cost saving, high performance and a flexible manufacturing system (FMS) are becoming important issues. **Table 1** summarizes customer needs which are needed of the specialty steels.

Regulation of exhaust gas requires special equipment which causes the weight increase of automobiles so that a light-weight car is required. In addition to the shift from front engine rear drive (FR) cars to front engine front drive (FF) cars, rationalization of parts structure and application of light-weight material, strengthening and new material are adopted. As for steels, strengthening and higher surface and internal quality are required.

To decrease the noise of the car, the control of sympathetic vibrations from the standpoint of structure and the absorption of sound and vibration are tried. As for parts made of wire rods or bars, the decrease of clearance at the rotating part and the modification of precision are used. In case of gears, increased contact area by improving the accuracy of manufacturing gears and increased height or number of teeth are helpful to make gear noise low. Therefore, steels for gears are required to be low strain and low fluctuation of strain. High strength steel, such as with narrowly controlled hardenability and stable quality, are required.

With the energy crisis as a turning point, the automobile industry became aware of the importance of energy saving. As a result, saving fuel oil consumption through the improvement of engines and the decrease of running resistance were put into practical use. Examples of modified engine parts are the change of the rotating crank shaft from a cast to forged product, and a lighter connecting rod by adopting high strength steel rather than conventional steel.

Efforts to make lighter or more compact engines are continuing. As a result, higher engine power is obtained with the same size engines as before. As for the transmission, higher torque is required even though the volume is limited to the same size as before. Thus, the need to increase gear strength should be included with increasing the power of the engine. This power improvement corresponds to the tendency of consumers' needs for four wheel drive and turbo-chargers. To decrease driving resistance, steel radial tires have been applied. Ultra-fine wire which is drawn to only 0.2mm diameter with a strength up to 4 000MPa is incorporated in the

Table 1 The background of customer's needs and the correspondence of steel technology

The background of customer's needs			Modification of steel
Problems	Corresponding step	Content	
1. Keeping of international competition power (globalization of manufacturing system)	•Cost reduction	•Shortening or omission of heat treatment (quench & temper, normalize, anneal, direct quench, high temperature carburizing, rapid carburizing)	•2nd or 3rd processability (cold heading, machining, soft nitriding, carburizing and fine wire drawaing)
2. Saving energy & natural resources	•Productivity	•Shortening of machining (peeling, precise forging, automatic machining, omission of machining, low quench strain)	•Quality level up (tight hardenability band,purity, toughness) •Anti-grain growth steel
3. Regulation of exhaust gas (the way how to minimize weight increasing by purifier)	•Improvement of specific fuel-consumption	•Saving of forging method (closed die forging, cold forging combination forging, utilize strain hardening, shape of cutting edge)	•Cost saving proposal (process short-cut, productivity)
4. Noise control	•Lighter car	•Improving reliability (endurance and performance for parts, such as engine, gear, suspension)	•Highly controlled steel (surface condition, segregation,decarburization and inclusion)
5. Construction of flexible manufacturing system (avairable for many kinds & small lot)	•Higher quality	•Reducing air resistance (steel radial tire)	•Precise rolling (section, straightness and shape of ends)
6. Customer's needs (correspondence to high quality and variety)	•More precise forming	•Strengthening and long life	•Steel with special function (anti-corrosion, electro-magnetic property and nonmagnetize)

fabric in the tire. The steel for such use is required to be specially controlled for decarburization, chemical segregation and inclusions.

One of the most notable car manufacturing systems is the FMS. The FMS, which is able to correspond to both a small-scale mass production and large-scale mass production, can be changed quickly. Through the system, quick action against changing of demand can be taken and productivity can be kept high.

To realize high productivity, it is important to shorten working time or to abbreviate processes. For example, the combination of cold forging with warm or hot forging enables parts manufactures to use less machining for product, near net shape product or integrated forging product.

As for forging methods, more precise forging products are obtained by the change of the forging method from hot forging to warm or cold forging or by the combination of hot and cold forging processes. As for the combination of forging method and material development, examples are as follows: (1) hot forging and micro-alloyed steel and (2) cold forging and micro-alloyed steel.

When heating the micro-alloyed steel for non-heat treatment use, often induction heating is applied as a source of heat. In the case of rapid heating, scale loss decreases which leads to more detailed control of surface condition than was required before. Aiming at a chipless process, closed die forging of parts are increasing and it becomes necessary to raise the precision of each cut piece. As a result, restrictive cutting is becoming more popular and so the straightness and the section of raw materials require more detailed control. Unmanned machining is one of the important ways to raise productivity, and now it is prevailing. In a 24 hour a day production process, the tip disposability at machining is regarded as very important.

For the FMS, the merit of abbreviating a process is not only the reduction of cost, but also the merit of shortening total manufacturing time.

To realize more functional cars, strengthening and longer life of parts are required. As for steel, much more improved function may also be required.

3. Sumitomo's New Products and Technologies of Bars and Wire Rods

New products and technologies, developed for the above-mentioned customers' needs and customers' merits, are shown in **Table 2**.

The aims of developed steels are classified into four categories: (1) saving energy and natural resources, (2) high productivity, (3) high quality, and (4) support to the secondary or tertiary processing.

3.1 Saving Energy and Natural Resources

Developed steels omissible heat treatments are as follows: (1) micro-alloyed steels for hot forging or cold forging are able to omit quenching and tempering, SUC series, (2) control rolled micro-alloyed steel for direct-machining use is able to omit quench and temper after rolling, (3) direct normalizing (DN) steel or direct annealing steel are able to omit normalizing or annealing, and (4) less work hardening Al-killed steel, SNH05A, B shows excellent cold -forgeability and this allows it to eliminate the soft -annealing process prior to cold forging without deteriorating die life or formability.

In favor of the precipitation hardening of vanadium carbo-nitride, high tensile micro-alloyed steel has equal mechanical properties to quench and tempered steel. Micro-alloyed steels are classified into two groups. One is for hot forging, the other is for direct machining.

Micro-alloy steel for hot forging use is able to get enough mechanical properties by the controlled cooling after hot forging. Micro-alloyed steel for direct machining use in as-rolled condition has equal mechanical properties to quench and tempered steel. Both micro-alloyed steels are controlled for chromium, manganese and vanadium content in consideration with the balance of strength and toughness.

Machinability or tip disposability improved micro -alloyed steel, such as sulfur, lead and calcium, separately or in combination, are also applied. The microstructures of micro-alloyed steels are mostly ferrite and pearlite, therefore, impact value and yield ratio are often lower than those of quench and tempered steel. For parts requiring toughness, the following three points are considered.

(1) Fine microstructure through forging condition,

(2) strengthening of weak micro-structure, ferrite, by the addition of alloying element such as silicon and vanadium, and (3) more toughness with decreasing carbon content.

Micro-alloyed steel for bolts was developed to omit quench and temper treatment of JIS 7T or 8.8T class bolts. This wire rod, after achieving required strength by the control of rolling and cooling, is adjusted to designated strength by cold drawing.

The remarkable merit of this procedure is that it realizes a big abbreviation of manufacturing process, suggesting much more wide application in the future. Micro-alloyed steel for cold forging improved in mechanical properties, especially elongation and toughness.

Free-cutting steel or precise rolling steel are helpful for the simplicity of the manufacturing process. The former, with decreased contents of sulfur and finely dispersed lead grain, can manage both good cold heading ability and improved machinability. The latter can obtain ultra-high dimensional accuracy of ±0.1mm (for 18.0-70.0mm diameter round bar) by three side rolling of the super finishing mill (SFM). Precisely rolled steel bar can be substituted for cold drawn bar or peeled bar. Precisely rolled round bar requires not only the accuracy of shape, but also the control of surface condition such as surface defects or decarburization. Hot rolled precise round bar is inferior to cold drawn bar in shape and the depth of surface defect or decarburization. However, several merits are expected such as the improvement of productivity in hot closed-die forging and the omission of cold drawing or peeling.

The addition of a small amount of boron can reduce the addition of alloying elements for hardenability. As for hardening boron steel, the best use of boron is expected in the following two ways: (1) boron raises the hardenability of tooth root, and (2) boron improves the toughness of the case hardened layer. Developed case hardening boron steel "SUMI-ALLOY EM420", as a substitute for SCM420, has been used for transmission gears of trucks for more than ten years.

Boron, without affecting flow stress, elevates hardenability remarkably with decreasing carbon content. This is the reason why boron steel is appropriate for cold forging use. Low carbon boron-added steel can omit annealing before cold forging. Molybdenum-free high tensile structural steels are applied to the parts of suspension members. Boron-added steel with high strength and toughness (HITS) was developed for parts of construction machines to realize both cost reduction and high quality. This steel shows equal to or better properties than nickel-chromium-molybdenum steel in toughness, anti-crack in the field and induction heating hardenability.

3.2 Productivity

The consumption of free cutting steel for machine structural use is increasing year by year as automatic or unmanned machines prevail which pay much attention to chip disposability. Sumitomo can supply every kind of free cutting steel containing sulfur, lead and calcium, separately or in combination. At present, free cutting steel is applied to vital suspension members, minimizing the decrease of toughness. Sulfur-free cutting steel is effective in improving tool life of high-speed steel tools. Calcium-free cutting steel is fit for high-speed machining with carbide tools. Sulfur-lead-calcium free cutting steel is especially effective not only for high-speed machining, but also has excellent chip disposability even at slow-speed machining.

Control of austenite grain coarsening on carburizing is an important problem. Carburizing parts after cold forging is increasing recently as a result of progress in cold forging technology and also as a requirement of cost reduction. Concerning carburizing of cold forging parts, it is necessary to suppress austenite grain coarsening during carburizing. Quenching strain which is sometimes found in carburizing or quenching gears causes leaning contact, vibration and noise. In order to avoid these problems, surface hardening methods without quenching are desirable. Soft-nitriding is recommended among desirable hardening methods.

While conventional steel does not show enough depth of the soft-nitriding layer, developed steel shows sufficiently deep case depth and appropriate case hardness or core hardness. Case hardening alloy steels for gear use are requested to reduce or to stabilize quench distortion and also requested to be chemically homogeneous among or within lots. To reduce distortion within every heat, continuous casting is recommendable. A combination of vacuum arc degasser (VAD), which is suitable for narrow Jominy band steel, and continuous casting is effective to stabilize distortion.

3.3 Higher Quality[7)~10)]

Corresponding with the tendency "lighter weight and higher performance of automobiles", Sumitomo has been developing several kinds of steels as follows:

high-strength gear steels, high-fatigue stress spring steels, anti-delayed fracture steels, and long-life bearing steels. Among high-strength gear steels, SUMIALLOY CM201 is the most cost competitive

Table 2 Aim of application for automotive part examples in Sumitomo's new bars and wire rods(1)

		Name	Aim of application: 1. Process shortening or abbreviation ① Quenching	② Tempering	③ Normalizing	④ Annealing	⑤ Carburizing	⑥ Cold drawing	⑦ Machining	⑧ Peeling	2. High productivity ① Presice forging	② Cold forging	③ Machining	④ Convert steel	⑤ Hardenability	⑥ Low strain	⑦ Cost reduction	3. High quality ① High strength and toughness	② High cleanliness (low oxigen)	③ High fatigue strength	④ Abrasion resistant	⑤ Anti-delayed fracture	⑥ Anti-relaxation	⑦ Anti-break	⑧ High quality control	Application
1 Saving energy, saving natural resources	1) Shortening of heat treatment	1. Micro-alloyed steel (cold drawing and direct machining use)	◎	◎												○	◎									Shaft
		2. Micro-alloyed steel (hot forging use with high toughness)		◎												○	◎									Spindle Knuckle Arm
		3. Micro-alloyed steel (hot forging use with high endurance limit)	◎	◎												○	◎									Connecting rod
		4. Micro-alloyed steel (cold heading bolt)	◎	◎		○		○								○	◎									Bolt
		5. Micro-alloyed steel (cold forging part)	◎	◎		○		○								○	◎									Ball tie-rod
		6. Direct normalizing steel			◎												◎									Axle shaft
		7. Direct annealing steel				◎		○									○									Shaft
		8. Less work hadening steel				◎						◎					◎									Speaker yoke
	2) Process shortening	9. Free cutting steel for cold heading quality										◎	◎				○									Cold heading
		10. Presice bar & wire rod						○	◎	◎	○						◎									Roller, Pin
	3) Saving alloying element	11. Boron added steel for case hardening use														○	○									Gear
		12. Boron added steel for bolt				◎		○				○					◎									Bolts
		13. Boron added steel for medium carbon range													○		◎	○								Knuckle
		14. High strength & toughness boron steel												○			◎	◎		○	◎					Link
2 Productivity	1) Machining	15. High machinability steel (Ca-S-Pb steel)											◎				○									Crank
	2) Case hardening	16. Anti-grain growth steel									○	○				○	○		○	○						Gear
		17. Rapid carburizing steel					◎										○									Gear
		18. Cold forging steel for high frequency quench		○							◎	◎		○	○		◎		○	○						Outer lace
	3) Constant or low strain	19. Soft nitriding steel	○	○												◎	○				○					Internal gear, Stationary gear
		20. Tight controlled hardenability steel													◎	○			○							Gear

◎ : Excellent, ○ : Good

steel for improving the fatigue strength at tooth root by eliminating abnormal structure. Shot peening produces a high-strength gear.

Anti-delayed fracture steel was developed for high-tensile bolts up to 1 470MPa, named ADS. High-tensile stress, high toughness and good anti-delayed fracture characteristics were achieved by specially controlled steel making, rolling and chemical composition. Chemical compositions (low phosphorus, low sulfur, high molybdenum, niobium addition) are designed to reduce boundary segregation, to keep fine grain and to give high tempering temperature.

Table 2 Aim of application for automotive part examples in Sumitomo's new bars and wire rods(2)

		Name	Aim of application: 1. Process shortening or abbreviation ① Quenching	② Tempering	③ Normalizing	④ Annealing	⑤ Carburizing	⑥ Cold drawing	⑦ Machining	⑧ Peeling	2. High productivity ① Presice forging	② Cold forging	③ Machining	④ Convert steel	⑤ Hardenability	⑥ Low strain	⑦ Cost reduction	3. High quality ① High strength and toughness	② High cleanliness (low oxigen)	③ High fatigue strength	④ Abrasion resistant	⑤ Anti-delayed fracture	⑥ Anti-relaxation	⑦ Anti-break	⑧ High quality control	Application
3 Functional quality	1) Strengthening	21. High strength gear steel									○	○			○			○	○	◎						Gear
		22. High endurance spring steel																○	○	◎		○	◎			Spring
		23. High endurance valve spring steel																○	◎	◎	◎					Valve spring
		24. Anti-delayed fracture steel																○		○		◎				Bolt
	2) Endurance	25. High endurance bearing steel																○	◎	◎						Bearing, Water pump shaft
	3) Others	26. Anti-break and wear resistance steel												○							◎			◎		Chisel
		27. Deep case hardening and wear resistance steel											○	○							◎					Bush
		28. Nonmagnetic steel																								Reinforced bar, Bolts
4 2nd or 3rd processing	1) Quality	29. Highly controlled quality steel									○	○						○	○	○					◎	Cold heading, Near-net shape
		30. Surface quality assured wire rod				○		○			○	○					○								◎	Heavy duty cold heading
	2) Lubrication	31. Ca-Zn lubricant										◎														Heavy duty cold heading
		32. Non-phosphide teflon lubricant (S-S LUB)										◎										◎				High tennsile bolt
	3) Continuous processing	33. In-line bonderite process									○	◎					◎									Cold heading part
		34. Coil feeding machine															◎									Continuous hot former

◎ : Excellent, ○ : Good

3.4 Support to the Secondary and Tertiary Processings

Bars and wire rods usually become the final products through the secondary and tertiary processings. The forging process is one of these processings. Whereas as-rolled materials are cut and each of them are used as important structural parts, perfection of every part of the steel is extremely important. Thus bars and wire rods require quality through the whole length. Given this background, Sumitomo has been making efforts for quality assurance of the entire length and total quantity, going back to not only rolling process but also steel making and blooming processes. With recent development of near net shaping, complex forming and high forming reduction, quality assurance level is required on raw materials. These bar and wire rods are called "highly quality controlled steels" as in **Table 1**.

Sumitomo has been making an effort to develop high quality raw materials and also has been developing technologies to support the secondary and tertiary processors. The following are the examples: the development of Ca-Zn lubricant technology; non-phosphorus lubricant, named "S-S LUB"; in-line bonderizing equipment which contributes to efficiency and continuation at the secondary and tertiary processors.

Developed coil-feeding equipment for a hot-former, named Coil Feeder, can supply bar in coils, instead of only bars, improving production efficiency. This coil feeder can control forging weight variation of forged products to within one-third of the usual process by minimizing backlash as much as possible and electrical synchronization with the hot-former.

4. Introduction of Testing Machine

Bars and wire rods after processing are often applied to very important automobile parts. Therefore, it is necessary to evaluate the parts with a cut off specimen or a finished part. Effort has been made to fulfill the line-up of testing machines for evaluating various parts. For basic analysis, SIMS (Secondary Ion Mass-Spectro meter), A-TEM (Analytical Transparent Electron Microscopy), EB (Electron Beam melting), Thermec Master (high temperature flow stress and ductility), and Dynamic Fracture tester are available in Sumitomo. As for evaluation of actual parts, X-ray Diffract meter, X-ray Stress analyzer, Roller Pitching tester, Medium high temperature contact stress fatigue tester, power circulating type Gear Testing machine, Drop Weight type Impact Fatigue tester, Deformable Formaster and Hydrogen analyzer at various elevated temperatures are available. Among them, the attractive point of Sumitomo's original Gear Testing machine is that it can evaluate the strength of a gear of arbitrary size within a limited size range.

The impact fatigue tester can be used to evaluate gear assembly such as differential gear unit and suspension member. Recently, the Forging Simulator has been introduced to supply various technical information and data on cold forging for gears.

5. Trend of New Products

5.1 Micro-Alloyed Steels[13)~17)]

Micro-alloyed steels have been developed to omit quenching and tempering. Derivative merits of micro-alloyed steels are prevention of strain on quenching, decrease in stock, reduction of handling times and reduction of delivery time.

Initially developed vanadium-added medium carbon steels laid the foundation for micro-alloyed steels and the main usage was as an application for crankshafts and connecting rods that required little toughness, as shown in **Fig. 1**. In order to apply micro-alloyed steels to suspension parts, high toughness was required. As a result, highly tough micro-alloyed steel with fine micro-structure was developed by using fine carbides, nitrides, sulfides and oxides.

Two methods for obtaining fine microstructure are: (1) obtaining fine austenite grain at reheating of hot forging, and (2) increasing precipitation of ferrite inside austenite grain. Method (1) is comprised of finely dispersed nitrides like Ti(CN), sulfides and oxides like inclusions.

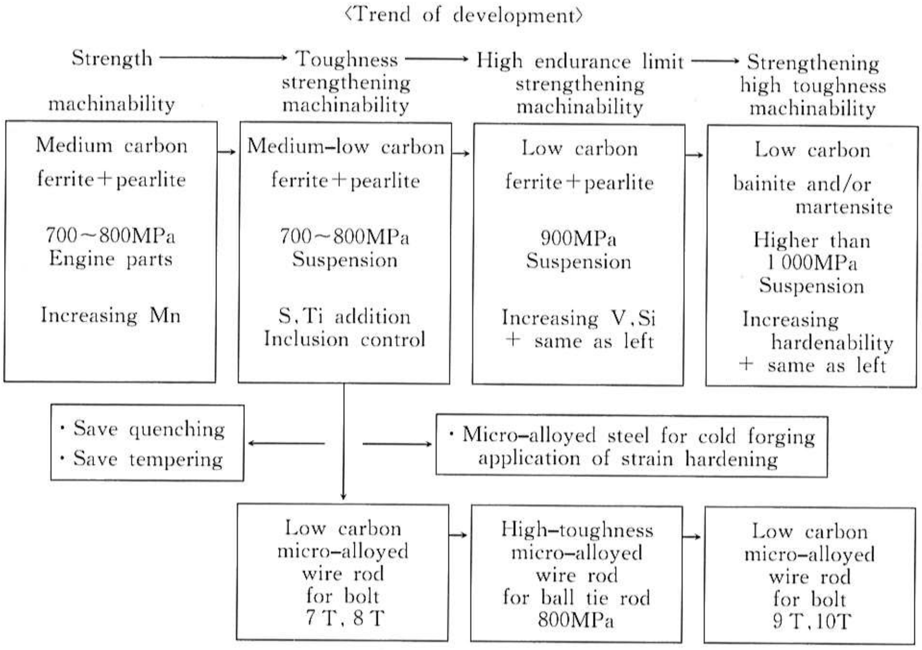


Fig. 1 The flowchart of developing micro-alloyed steel for non-heat treatment use

Figure 2 shows that only 0.007 mass% titanium makes austenite grain finer for micro-alloyed steel of 0.35C-0.30Si-1.6Mn. **Figure 3** shows the mechanism of grain refining by MnS.

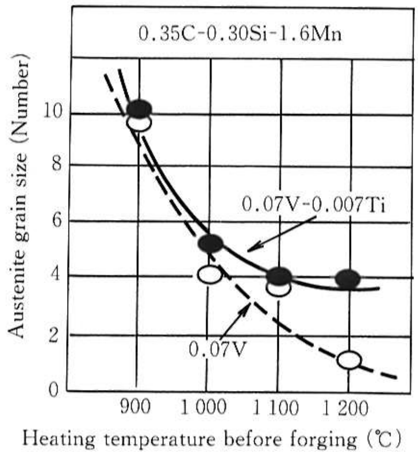


Fig. 3 Illustration of MnS refining the grain size

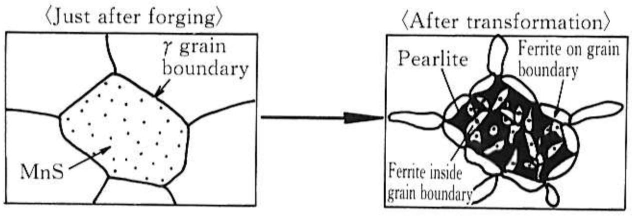
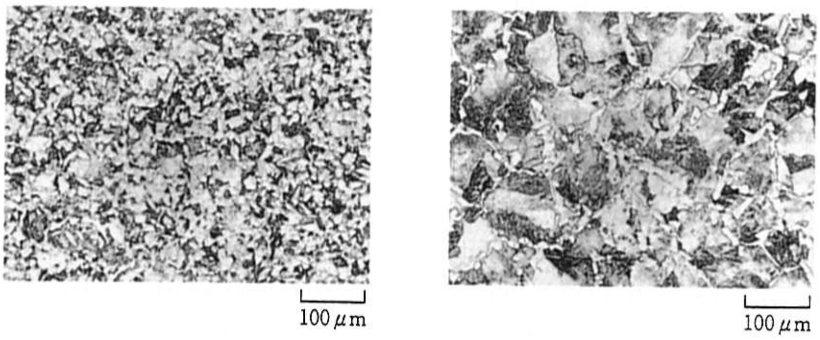


Fig. 2 The effect of Ti addition on austenite grain size

Photo 1 shows the microstructure of micro-alloyed steels, in comparison with LMIC80S1 and S45CV. **Figure 4** shows the improvement of low temperature toughness by MnS and by low carbon. The addition of sulfur to micro-alloyed steels is also useful for improvement of machinability but promotes anisotropy of mechanical properties.

As ferrite and pearlite microstructure does not have tensile strength higher than 900MPa, micro-alloyed steels of bainite-type microstructure were



LMIC80SI (S added) S45CV (Conventional micro-alloyed steel)

Photo 1 Microstructure of micro-alloyed steels, LMIC80S1 and S45CV

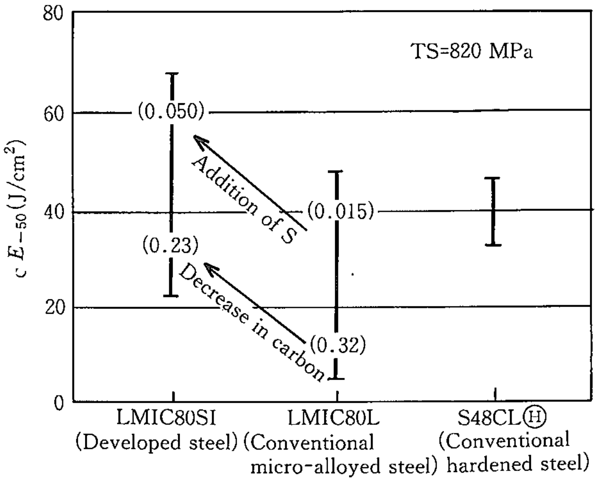


Fig. 4 Low temperature toughness of LMIC80S1

developed for 1 000MPa class in order to meet requests of further high strength and toughness. **Figure 5** shows toughness of low-carbon, bainite-type, micro-alloyed steel. Though fatigue strength increases with hardness, to raise hardness is undesirable from the point of machinability. To increase fatigue strength of parts without raising hardness, high endurance, limit-type, micro-alloyed steel is required.

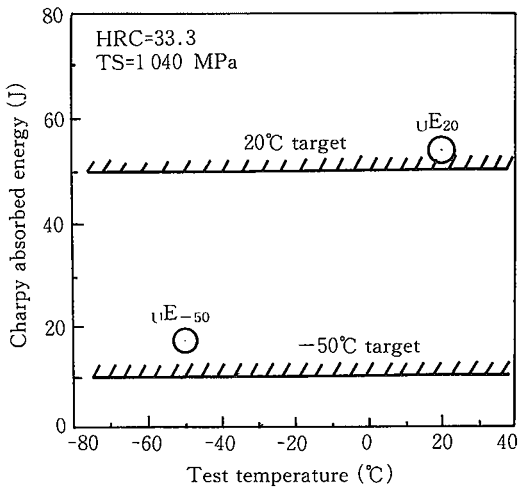


Fig. 5 The impact value of low-carbon bainite type micro-alloyed steel

Figure 6 shows an illustration of improvement of endurance limit through the hardening of weak ferrite by means of the increase of silicon, vanadium and the decrease of carbon content.

The endurance limit of this developed steel is higher than that of conventional micro-alloyed steels and equal to that of quench and tempered steels. **Figure 7** shows that developed micro-alloyed steels improved machinability.

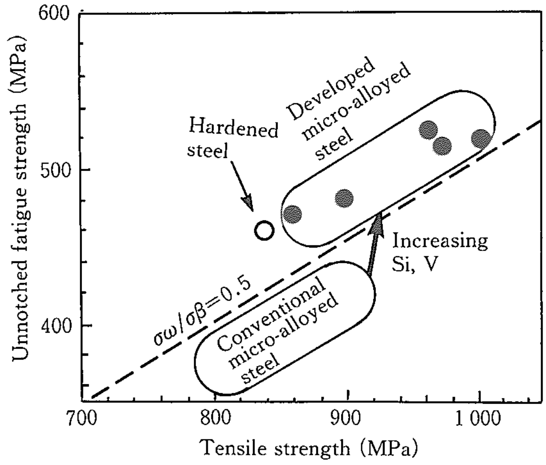


Fig. 6 The fatigue strength of high fatigue limit ratio type micro alloyed steel

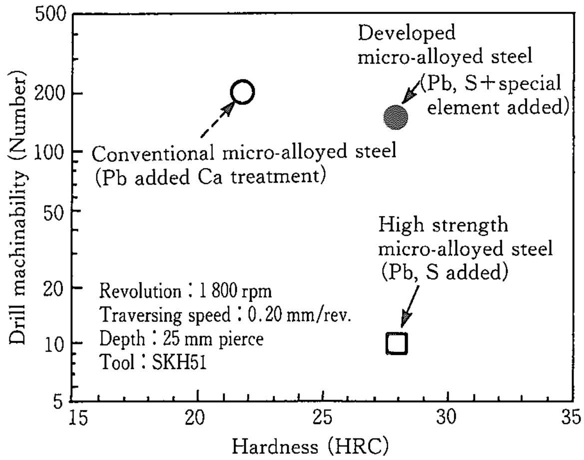


Fig. 7 Life of drilling tool of high machinability type micro-alloyed steel

Micro-alloyed wire rods can meet required tensile strength by control of chemical composition, hot rolling and work hardening during cold drawing. Micro-alloys like niobium, vanadium and boron are added to low-carbon manganese steel to get appropriate hardness and toughness. Controlled rolling achieves longitudinally fine and uniform microstructure. As an increase in hardness during cold drawing affects little the flow stress at cold heading, the application of this wire rod 1 is an effective method in order to increase the hardness of cold forged parts due to minimizing the increase of deformation resistance. This phenomenon is well known as the Baushinger effect.

Work-hardened cold-heading bolts have formerly been limited to application as low grade bolts, such as JIS 6T class. At present, owing to both the cost reduction and the progress of heading technology, the applications have been extending to high hardness level (for JIS 7.8-8.8 class). Micro-alloyed steels for cold-heading quality, which allow plastic deformation and whose chemical composition is designed to easily form fine zinc-phosphate layer, were developed. In spite of these developments, the applications of micro-alloyed wire rod are restricted because of the decrease of die life or ductility. In case of stud bolts, thread rolling of both ends is the main deformation process, so an increase of hardness is of little importance. However, as for the application of JIS 7.8-8.8 class bolts, micro-alloyed wire rods are only applied for small hexagonal bolts with low reduction. An application of this steel is expected in the future for bolts with hexagonal vent and cross vent. An obstacle against application is the increase of hardness of micro-alloyed wire rods, the higher bolt grade. As to consider non-heat treatment bolts at high tensile grade, integrated examination of various technologies such as lubrication, tool, and process is necessary.

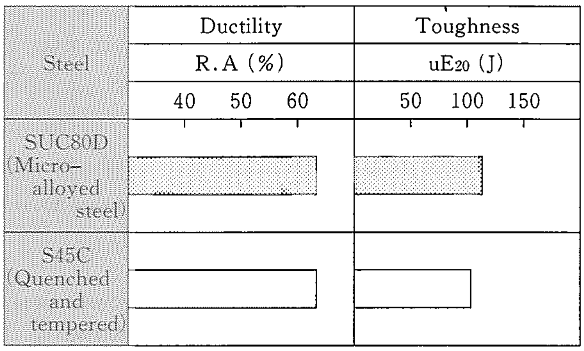


Fig. 8 Ductility and toughness of type SUC80D micro alloyed steel for cold heading guality

5.2 Steel for Cold Forging[18)~34)]

In the case of designing chemical composition for a steel, which is manufactured through the hot forging process, the function of finished parts is considered much more than hot forgeability. On the other hand, when manufactured through the cold forging process, it is necessary to pay attention not only to the function of the finished parts, but also the deformation resistivity and the deformability. This is because the deformation resistivity of cold forging is much higher than hot forging and is apt to become difficult to deform by the work hardening phenomenon. But the cold forging process is effective for realizing near-net-shape products economically in mass production. Recently, to satisfy both lowering of deformation resistivity and excellent shape, a combination of forging processes is prevailing, namely a combination of cold forging after hot or warm forging. The forged parts are extensively used for engines or suspension members including bolts for automobiles or construction machines. In the case of automobile parts, stable strength and toughness are required because many parts are specified as very important security parts. In addition, conjunctive bolts are practically formed by cold forging. As the cold-forging technology progresses, the need to precisely form more complicated shapes are increasing, and so higher deformability and lower deformation resistivity are required. For cost reduction and shortening of manufacturing time, it is oriented to abbreviate a process, for example, cold drawing and annealing, or both. Therefore, at the forging process, improvement of tool life and die life become important elements for increasing productivity. The application of cold forging is restricted in the amount of deformation, deformed shape and the size of products. In order to ease these restrictions, work has been done on various points, such as the control of chemical composition, especially carbon content and the other alloying elements, and rolling condition.

There are four subjects in forging technology: improvement of yield rate, increasing productivity, higher precision and cost reduction. In order to improve yield rate and productivity, higher speed production has been made by introducing automatic equipment and adopting the pre-forming process. In the forging process, higher precision is important for making finished parts. This is a concrete example for improving the precision of hot forging, closed-die forging or a combination of hot and cold forging.

In the movement of globalization, to meet the exigencies of the moment, cost reduction is important. Many kinds of methods have been practical for cost reduction, including omission or modification of quench and tempering process, drawing, annealing, and so on, reduction of the material cost, and improvement of tool life by adopting free-cutting steel. **Figure 9** schematically illustrates the relationship between C content and hardness of annealed material.

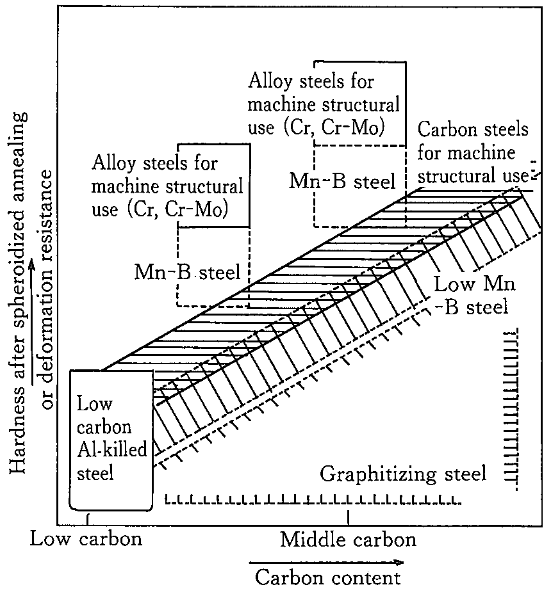


Fig. 9 Relationship between carbon content and hardness after spheroidized annealing (Illustrative comparison among steel grades)

The development of low-carbon Al-killed steel for cold forging is as follows. To develop the low-carbon Al-killed steel with good forgeability, it is important to minimize the amount of free carbon and nitrogen in solution which is not forming carbide and nitride without spending extra money. This is because the free carbon and nitrogen in the steel cause strong work hardening when the steel temperature rises. In order to fix the free nitrogen, adding titanium is more effective than aluminum. As a method to decrease the amount of carbon in solution, an addition of chromium is efficient because chromium forms carbide. There are some other ways to fix the free carbon and nitrogen such as controlled rolling and aging treatment. Examples of development of the low-carbon Al-killed steels which can be forged without annealing are reported as follows:

(1) 0.78% chromium aims to decrease the amount of carbon in solution dramatically. Chromium can prevent strain aging from decreasing the amount of carbon in ferrite. Aluminum addition in surplus minimizes nitrogen in solution.

(2) Strain aging is suppressed by modifying SWRCH8A's chemical composition, decreasing the amount of silicon and manganese, increasing the amount of aluminum, and controlled rolling. Without annealing, the new steel can obtain the same hardness level as conventional SWRCH8A with spheroidized annealing.

(3) Adding excess aluminum to fix free nitrogen also fixes free carbon in ferrite of low-carbon Al-killed steel. It is introduced to reduce the amount of carbon in solution and to suppress strain aging. Aging after rolling causes excess carbon in ferrite to precipitate into cementite. Consequently, strain aging is kept down and the steel with less work hardening can be produced. **Figure 10** illustrates the new steel is work hardening. The figure compares conventional, developed steel and developed steel with aging.

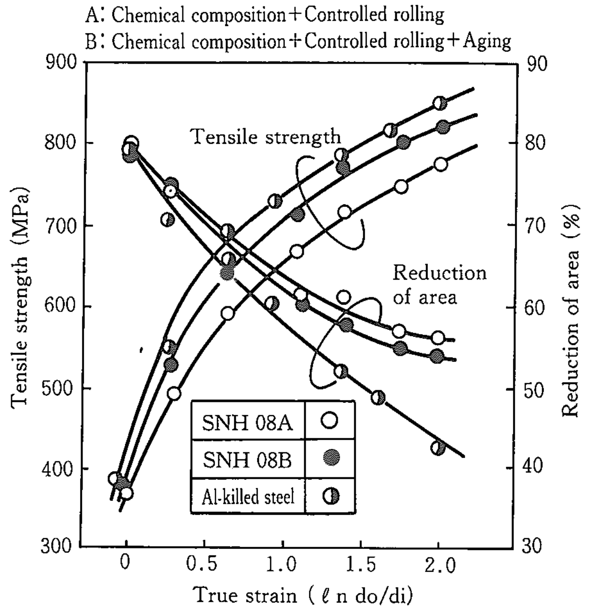


Fig. 10 Comparison of work hardening (Conventional steel, developed steel and developed steel with aging)

By restraining the age hardening caused by free carbon and free nitrogen, the steel can ensure the ductility after highly reduced cold working. As a result, rivets that have high strength and enough ductility can be obtained by repetition of drawings without annealing. The new steel can be used as speaker yoke which is upset over 80% working ratio.

Developed boron-added steel decreases hardness compared with conventional carbon steels and alloyed steels. When medium-carbon structural steel is replaced with low-manganese boron-added steel, the decreased amount of hardness will be about 15%. If graphite is precipitated in the steel, a greater decrease of hardness can be expected. To precipitate graphite leads to some problems such as heat treatment condition and chemical composition

Table 3 The case of development of low-carbon Al-killed steel for rivet

Steel	Chemical composition		Wire TS (MPa)	Production process					Characteristic for rivet		Total evaluation
	C	Mn		Drawing	Annealing	Drawing	Cold forging	Annealing	Tensile shearing fatigue	Slant strike test	
A	0.13	0.43	382	–	–	○	○	○	×	○	×
B	0.13	0.45	421	○	○	○	○	–	×	△	×
C	0.20	0.41	421	–	–	○	○	○	×	△	×
D	0.13	0.43	510	–	–	○	○	–	○	×	×
E	0.08	0.37	549	○	–	○	○	–	○	○	○

A~D : Conventional steel, E : Developed steel

that must satisfy both required hardenability and precipitated graphite which exist homogeneously. In spite of these difficulties, the steel is expected to have the great advantage that "it is soft when it is cold forged, and it can obtain high strength by quenching after forging".

Figure 11 shows the circumstances of developing the steel for cold-heading bolt use. For 7T-8T class bolts, conventional carbon steel has been used. Recently, production of 7T-8T class bolts made of boron-added steel with a simple manufacturing process has been investigated. On the other hand, reducing material costs and simplifying the manufacturing process of 9T-10T class bolts, which are now made of conventional alloyed steel has been investigated. Furthermore, there is a need for 12T or higher strength bolts. The new steel, ADS-2, had been developed for 12T class bolts. Now the steel for 13T class bolt, ADS-3, is investigated. To ensure higher strength, it is necessary to take delayed fracture into consideration. The new steel's chemical composition is designed to consider the following factors: (1) finer grains, (2) maintaining tempering temperature, and (3) decreasing grain boundary segregation. Recently, anti-delayed fracture of new steels have been verified by the progress of hydrogen analysis technology. Also, instead of strengthening the bolt, fastening below the plastic region has been applied to avoid the delayed fracture of high tension bolts.

As shown in **Fig. 9** and **Fig. 11**, boron-added steel can satisfy not only cost reduction of material but

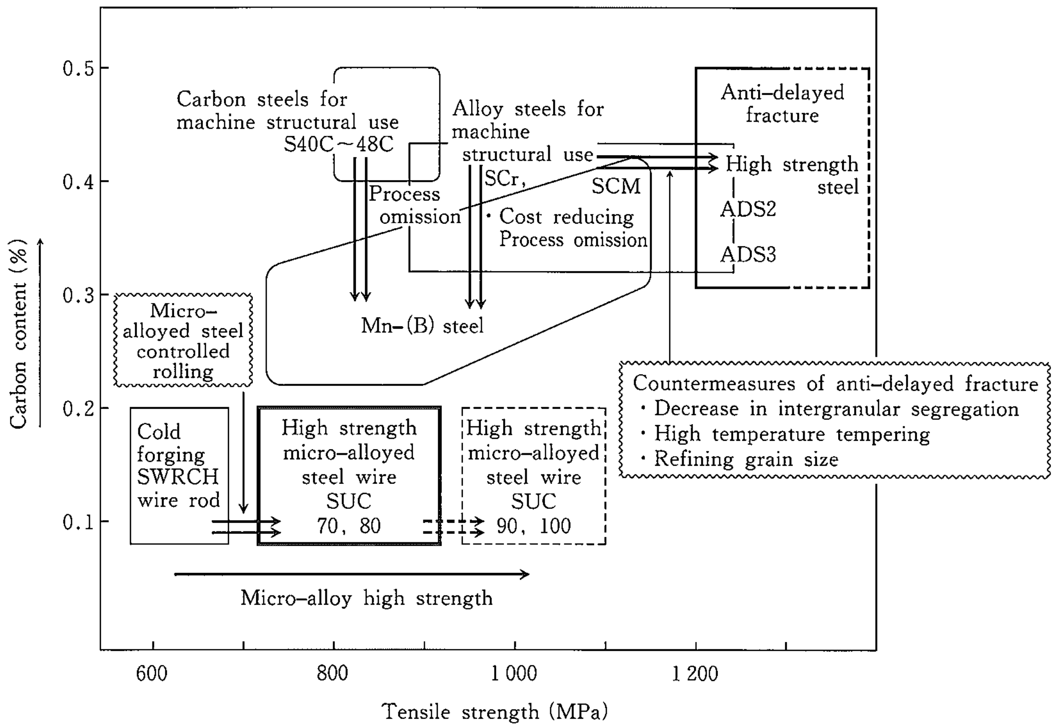


Fig. 11 Circumstances of developing the steel for cold heading bolt use

also could be applied to many parts using good deformability with increasing hardenability. The addition of boron hardly increases the flow stress so that boron is the most effective element for precise hot, warm and cold forging. **Table 4** summarizes the features of boron-added steel for the reader's reference.

Boron-added steel has good toughness. The followings are the examples:
(1) Improvement of cracking load in the three-point bending test including carburized layer (**Fig. 12**), and (2) improvement of fracture toughness of the steel which was tempered at low temperature (**Fig. 13**). The mechanisms of these phenomena will be investigated in the future analysis.

Here is an example for improving productivity. The combination of cold forging and machining has been applied to the parts which were fully machined as usual. In other words, steel which has good cold-forgeability and machinability has been needed.

Chemical composition (mass %)

	C	Si	Mn	Cr	B
A	0.22	0.10	0.80	0.01	–
B	0.22	0.10	0.82	0.49	–
C	0.21	0.10	0.83	0.99	–
D	0.23	0.10	0.85	1.50	–
E	0.21	0.09	0.80	0.98	0.0025

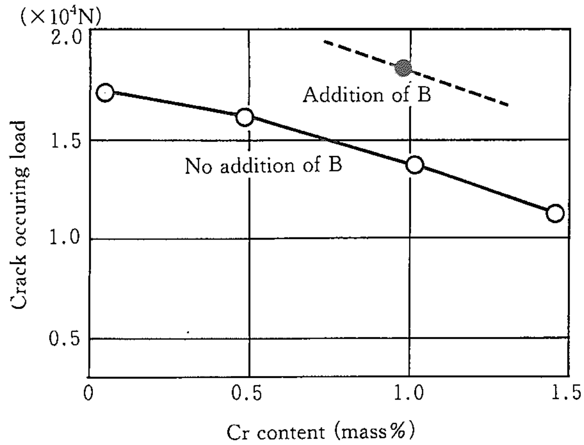


Fig. 12 The effects of Cr and B on crack occuring load in three points bending test

Table 4 Characteristics of Boron-steel

	Item	Content
Hardenability	Improvement of hardenability	•Special Jominy curve
	Effect of carbon content on hardenability	•Use of low carbon steel
	Boron content and hardenability	•Good hardenability at boron content more than 0.0003%
	Stability of hardenability	•Equal to conventional steel
	Thermal history and hardenability	•Restoration by reheating of quenching
	Control of Ti, Al, N and other tramp element	•Hardenability, prevention of grain growth
Strain	Quenching strain	•Special Jominy curve
Quenching crack	Quenching crack	•No problem •Improvement of shape •Decrease in Mn content •Self temper quenching •Attention of tool mark •Prevention of partial oxidization •Uniform cooling of surface
Surface hardening	Characteristic of surface hardening	•Decrease in carburizing surface hardening •Good induction hardening •Constant of soft nitriding
Processability	Deformation resistance	•No problem
	Process annealing	•Omission
	Hot workability	•No problem
	Machinability	•No problem
Mechanical properties	Tempering temperature	•Easy to softening by tempering •Constant of residual stress
	Carbon equivalent	•Poor softening resistance of tempering •No problem of welding •Hardness
Characteristic of fracture	Fracture toughness	•Low temperature tempering having an effect
	Characteristic of delayed fracture	•No problem

Aim : Cost reducing by change of steel grade
Characteristic :
(1) Example (mass %)

Steel	C	Si	Mn	Ni	Cr	Mo	Nb	B
HITS	.41	.23	.45	–	1.0	.49	.03	Added
SNCM431	.30	.26	.78	1.6	.75	.16	–	–

(2) Composition designing
- Intergranular strengthening……Decrease in amount of P, S, Mn, Mo, Addition of B
- Softening resistance of tempering………………Addition of Cr, Mo, Ti
- Surface hardening and improving of hardenabilty ……Addition of C, Cr, Mo, B
- Cost reduction………………No addition of Ni

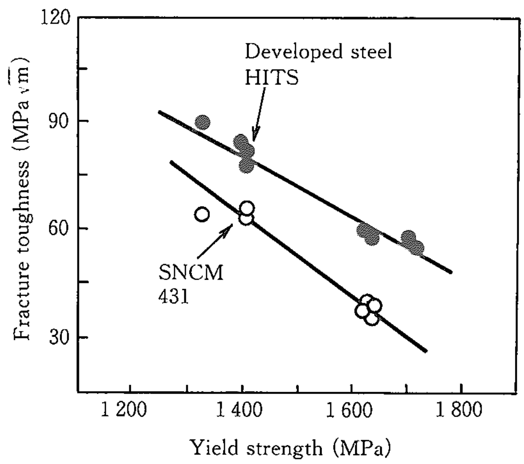


Fig. 13 Fracture toughness values of HITS steel

The ductility of steel is important for cold-forgeability. On the other hand, to improve machinability, addition of "free-cutting elements" like sulfur and lead which are inclusions in steel is effective. These properties, forgeability and machinability, conflict with each other. Recently, however, the steel which has both properties has been developed.

Developed steels are as follows:

(1) Exclusion of alumina (Al_2O_3), because alumina has a bad influence on both cold forgeability and machinability.

(2) Reduction of the amount of sulfur, because it dramatically makes cold-forgeability inferior while sulfides improve the machinability.

(3) Fine and uniform dispersion of fine lead particles, because it improves machinability, especially tip disposability, and it hardly influences cold-forgeability.

Figure 14 indicates that including lead merely influences cold-forgeability. Addition of at least lead can improve cold-forgeability of steel while keeping machinability. Recently, machining has been operated automatically. Therefore, tip disposability has become more important and the new steel is advantageous to the disposability. In such case, the need for steel that has good cold forgeability and machinability might be increasing.

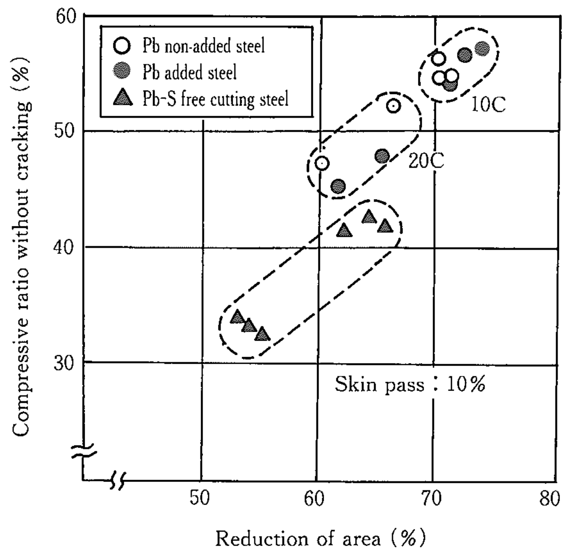


Fig. 14 High machinability steels for cold heading quality

5.3 An Attempt for the Strengthening of Parts Through the Combination of Material and Process

To put forth steel's strength performance lies on the combination of steel and process. Two examples of the combination are introduced.

(a) Strengthening by the combination of heat treatment[34]

Funatani explained combination of heat treatment as "combination of usual single heat treatment in order to give a part necessary properties", and introduced some examples. Recent work showed combinations of nitrization and laser hardening, nitrization and hardening by induction heating.

To strengthen the differential gear set, the combination of carburization and quenching and tempering after induction heating was applied. The gear requires cyclic impact bending strength at the tooth root, in low cycle condition. Improvement of the tooth root bending strength for carburized steel is achieved by decreasing phosphorus and manganese, and by the addition of nickel and molybdenum. They help both strengthening of grain boundary and also toughening inside the grain. On the other hand, induction heating after carburization results in formation of new boundary through carbide re-solution, carbide reprecipitation and recrystalization. Thus, the regeneration of grains, of which boundary segregation is less and finer than it used to be, seems to be caused by high strength. The relationship between bending rapture strength and grain size number shows linearity. Moreover an actual gear's bending test resulted in an improvement of 20% of the mean rapture strength in torque (**Fig. 15**).

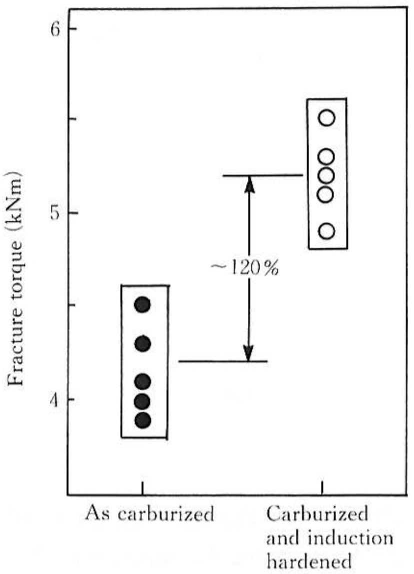


Fig. 15 Bending test results on actual gears

(b) Strengthening by forging after carburization[35)~37)]

Development of bevel gear with high fatigue strength was performed by forging after carburization. This development was realized using three technologies in combination: carburization of case hardening steel, direct quenching after forging, and near-net shape by closed-die forging technique. The development aimed to get high strength through thermo-mechanical treatment and to get ideal case profile of carburized gear; deep at tooth flank, shallow at tooth root where bending load and impact load apply and no hardened layer at tooth crest. Net shaped bevel gear after carburization was a big stride toward the ideal case profile mentioned above. As metal flaw begins at dedendum flank and finishes at addendum flank, so carburized layer varies thin or zero at gear root and thick between tooth flank and addendum flank. One example shows carburized thickness, 0.2mm at curvature of root radius and 0.4mm at tooth flank on a pitch circle. As for residual stress, usual carburization shows +100MPa tensile stress at the surface and maximum -400MPa compressive stress at 0.2mm inside from the surface. On the other hand, a gear made by forging after the carburization shows maximum -600MPa compressive stress on the surface. Due to the forging process, abnormal soft carburized layer seems to be minimized and so the ratio of strengthening after carburization to usual carburization becomes 199-266%. The strengthening mechanism is not clear, but the strengthening seems to be made up of grain size, thermo-mechanical processing including metal flow, and zero or nearly zero thickness of unusual carburized layer (**Table 5**).

Table 5 Bending strength at tooth root of forged gear after carburizing

Steel	(A) Carburizing Quenching Tempering Load (TON)	(B) Forging after Caburizing Quenching Tempering Load (TON)	B/A (%)
SCM418H	0.6	1.36	226
0.6Mo Steel	1.02	2.03	199
0.4Mo Steel	0.6	1.61	266

6. Summary

Sumitomo Metal Industries, Ltd. has corresponded to the changing of customer needs. Sumitomo has also been developing new products and new process technologies under the guidance of the customer.

In order to harmonize with society, safety, exhaust gas, noise and saving energy are all subjects we should give a great effort to manage. Requirements for steel will become much more strict and diverse than as of today corresponding to consumer needs. Considering these things mentioned above, Sumitomo will continue to improve its quality and to develop new products.

Kazuhiko Nishida

Dr. Eng., General Manager,
Material for Automotive Use,
Head Office

Phone: 06(220)5544

References

1) Y. Sugiyama: Jidosha-gijutu, **36** (1982), p.328
2) A. Dan-no: Toyota Central Laboratory R&D Review, **20** (1986), p.64
3) I. Iwasaki and I. Mizutani: Jidosha-gijutu, **41** (1987), p.593
4) K. Asano: Tanzo-giho, No.57 (1994), p.22
5) K. Nishida: Preprint for Bo-sen Forum by ISIJ, (1996)
6) M. Fujita, K. Nishida, M. Sakamoto, F. Nakasato and T. Ohno: The Sumitomo Search, No. 28, (1983), p.103
7) T. Mizuno, T. Matsubara, M. Ohno, M. Nakata, M. Suzuki and H. Hattori: Honda R&D Technical Review, **5** (1993), p.60
8) Y. Miwa, S. Shibata, K. Hanakawa, Y. Ikuno, K. Mihara and S. Sako: Mazda Technical Review, **8** (1990), p.130
9) T. Takayama, S. Hinotani, K. Izumi, Y. Kamada, M. Kondo and M. Mori: Preprint for the 39th Netushori-gijutu Seminar, (1994), p.19
10) Y. Kamada: Tokushu-ko, **43** (1995), No.3, p.43
11) H. Hagita and N. Nakao: Sumitomo Kinzoku, **45** (1993), p.90
12) S. Ogata, M. Yokoyama, M. Tomiku, T. Kuno and Y. Kawashima: Sumitomo Kinzoku, **39** (1987), No.3, p.77
13) C. Sudo and K. Nishida: Tokushu-ko, **40** (1991), No.12, p. 36
14) T. Kakizaki and Y. Kamada: Zairyo-to-process, **7** (1994), p.774
15) M. Hirai: Sumitomo Kinzoku Technical Report (Unpublished)
16) A. Hosono and K. Fujita: Isuzu Technical Report, No.90 (1993), p.90
17) Y. Murakami, H. Usuki, Y. Okada, T. Kumamoto and H. Ueno: Preprint for Jidosha-gijutukai, No.912 (1991), vol. 2, p.2-41
18) N. Sakaguchi: The 157&158th Nishiyama Memorial Lecture, (1995), p.163
19) J. Ishida: Denki Seiko, **60** (1989), p.66
20) Y. Wakunami, Y. Kamada, K. Toyama, K. Ohkawa and T. Tagawa: Nihon Kinzoku Gakkai-ho, **32** (1993), p.250
21) K. Shiwaku, S. Kuchi-ishi, Y. Yamada and T. Kawasaki: R&D Kobe Seiko Giho, **35** (1985), No.2, p.55
22) T. Tukamoto and H. Hagita: The 39th Shinsen-gijutu Bunka-kai, (1995)
23) K. Kajiyama, A. Aida, M. Fujita, T. Ohno and K. Aihara: Wire Journal, Nov. (1979), p.66
24) H. Matsumoto, F. Nakasato, N. Kuratomi, T. Kushida and T. Tsumura: CAMP-ISIJ, **7** (1994), p.1602
25) T. Hoshino, T. Fujita, A. Matsuzaki and K. Amano: CAMP-ISIJ, **8** (1995), p.634
26) N. Mizui: Symposium on Jidosha-zairyo co-sponsored by ISIJ and Jidosha-gijutukai, Oct. (1994)
27) B. Miyanaga: Kinzoku, **56** (1986), No.1, p.34
28) B. Miyanaga: Kogyo-zairyo, **36** (1988), No.14, p.60
29) T. Ohno, C. Sudo, K. Aihara, W. Takahashi and M. Take-uchi: Sumitomo Kinzoku, **35** (1983), No.4, p.113
30) M. Nakamura, H. Takeshita, J. Ko-arai, H. Matsuyama and S. Furusawa: R&D Kobe Seiko Giho, **33** (1983), No. 2, p.93
31) I. Machida, T. Takagi, Y. Umeno, Y. Yoshimura and S. Nakao: Honda R&D Technical Review, **5** (1993), p.80
32) N. Murai, K. Aihara and S. Hinotani: Sumitomo Kinzoku, **44** (1992), No.3, p.14
33) K. Nishida: Preprint for the 65th Lecture at the Technology of Plasticity, (1997)
34) T. Murayama, S. Magara and S. Ohara: Preprint for Jidosha-gijutukai, (1989), p.892
35) K. Orita, A. Mudagami, T. Masaki, S. Arimi, Y. Kamada, M. Uno, T. Takayama and N. Murai: Preprint for Jidosha-gijutukai Symposium, No.9415 (1994), p.18
36) S. Fushimi and S. Shimamura: Tetsu to Hagane, **78** (1992), p.1383
37) S. Fushimi, S. Umegaki, M. Uno, K. Nishida, K. Ohkochi and M. Kojima: CAMP-ISIJ, **7** (1994), p.1744
38) K. Nishida: Nihon Kikai Gakkai, Research Report of RC-132, (1997), p.72