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Development of Lead Free Micro Alloyed Steel for Crank Shafts

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Abstract

With rising conscious for environmental problems, elimination of lead which is generally considered as an environmental loading element from free-machining steel is required. It is well-known that lead improves machinability of steel, minimizing the effect on the mechanical properties. It might be exchangeable with other elements in terms of machinability. However, these elements often give problems to mechanical properties and productivities at consumers. Therefore, new free-machining steel was developed by minimizing MnS size and distributing them isotolopicly and it was verified that the developed steel had good properties in not only machinability but also mechanical properties. The developed steel was useful in steel requiring high strength and machinability such as crank shafts of engines.

1. Introduction

With the addition of lead, the machinability of steel is known to improve. This accounts for the wide use of lead for high strength steel for which machinability is required. Also, lead only slightly influences mechanical properties of steel. However, with the growing consciousness of environmental issues in recent years, there is a tendency toward eliminating lead because it is seen to be one of the pollutants of our environmental[1-2]. The demand has thus been strong for the development of steel machinablity without the addition of lead. If the problem is limited only to machinability, it is possible to resolve that demand with the addition of free-machining elements other than lead, such as Bi and S[3]. However, those free-machining elements have a great influence on mechanical properties, posing a problem in relation to the mechanical properties of steel, including fatigue strength and the users' productivity, as witnessed in forging.

This has led to the development of high strength steel in which machinability and mechanical properties can stand together by dispersing MnS in steel more minutely than before.

2. Concept of developments

It is a known fact that S is quite effective as a free-machining element which can be used in place of lead. However, MnS is produced in steel in large quantities when S is added. Since MnS is stretched in the steel in the processes of rolling and forging, the mechanical properties (of the steel) including fatigue strength are lowered, particularly anisotropically. This anisotropy is considered to bring many problems which are hard to identify in general mechanical tests as seen in an increase in the probability of cracking during the forging and quenching processes as performed by consumers.

To overcome the defect of stretched MnS, an attempt is often made not only to control the deformability of MnS but also to make the shape of the stretched MnS spherical. Te and Ca are considered effective for this purpose[4]. However, even if MnS is spheroidized (made spherical), mechanical properties are degraded in the end if the resulting MnS is large enough. Furthermore, the addition of a large quantity of spheroidizing elements often brings about worse effects than that of MnS, because it leads to the formation of clusters, the interposition of nonmetals besides MnS, and the lowering

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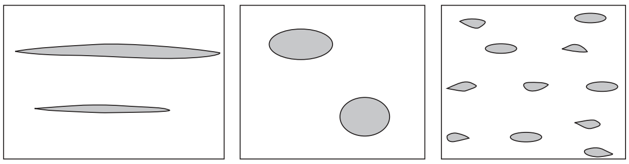


Fig. 1 Difference of MnS in size and distribution (image drawing)

of the ductility of the steel matrix.

Fig. 1 illustrates the basic concept of developments. That is, the simple addition of S results in the lowering of mechanical properties with MnS stretched. This is shown in Fig. 1 (a). The conventional methods were mainly to spheroidize MnS as Fig. 1 (b) shows. However, in view of the harmful effects of stretched MnS or spheroidizing treatment on MnS, to minimize the defects of S addition is directed by dispersing fine MnS. This can be seen in Fig. 1 (c).

3. Experimental methods

3.1 Test samples

Table 1 shows the chemical compositions of test samples. The base steel is what we call a free-machining base steel in which Pb is added to the micro-alloyed steel converted from S45C. The test material was melted in the 150-kg vacuum melting furnace, and forged to a diameter of 80 mm. Then, it was heated at 900 ˚C for 30 min., air-cooled (for homogenization of pre-forged structure), and wind-cooled at 1200 ˚C × 1 h (simulation of hot forging). As **Table 2** shows, hardness was adjusted to the same level.

3.2 Evaluation items and conditions

The items of evaluation include microstructure, machinability, and mehanical properties. In the microstructure, distribution and shapes of MnS were measured using an image processor. MnS observed under the microscope with 500 magnifications × 20 views, were rendered into a binary, and (a) the number of MnS, (b) the size of MnS (a diameter equivalent to a circle), and (c) an aspect ratio were calculated.

As machinability, (a) the drill life in an ordinary drilling, (b) the property in deep hole drilling using a long drill, and (c) the wear resistance in turning bars were evaluated. Tables 2 to 4 show the respective conditions. In the evaluation of the drill life in ordinary drilling, the accumulations of the hole depth until the drill was broken were measured in various peripheral speeds. Furthermore, the maximum peripheral speed that enables to drill an accumulated hole depth of 1,000 mm, that is, VL1000 (m/min), was measured as an index of machinability.

Table 3 shows the deep hole drilling test conditions using a long drill. In the evaluation of the property in deep hole drilling, a hole as deep as more than 10 times the drill diameter was drilled at a constant feed rate without step feeds for the removal of chips, and accumulations of the hole depth drilled were measured. Then the cutting forces (torque and thrust) were measured with the piezoelectric-crystal element type dynamometer.

Table 4 shows the turning test conditions. In the turning test, the long peripheral of a round bar was machined, and the wear width of major flank were measured at various cutting times. General machining conditions with a coated cemented carbide tool were set in peripheral turning. An optical microscope was used for observing and measuring the wear width of the major flank of tool in the evaluation.

Table 1 Chemical compositions of steel for evaluation (mass%)

Material	C	Si	Mn	P	S	V	Pb	Special element	HV
Base steel	0.45	0.26	0.80	0.019	0.023	0.10	0.16	—	237
Developed steel S2 (DS2)	0.45	0.25	0.92	0.018	0.097	0.10	—	Added	248
Developed steel S3 (DS3)	0.45	0.01	1.12	0.017	0.151	0.10	—	Added	236

Table 2 Test conditions for evaluation of the drill life in an ordinary drilling

Drilling conditions	Drill	Others
Cutting speed : 10-50m/min	3-mm dia.	Hole depth: 9mm
Feed: 0.25mm/rev	Tip angle: 118˚	
Cutting oil:	Material:	Tool life:
Water-soluble cutting oil	High speed steel	until breakage

Table 3 Deep hole drilling test conditions using a long drill

Drilling conditions	Drill	Others
Cutting speed: 18.8m/min	6-mm dia.	Hole depth:
Feed: 0.1mm/rev	Long drill	until 75mm
Dry method	Material:	Tool life:
	High speed steel	until breakage

Table 4 Peripheral turning test conditions

Machining conditions	Tool
Cutting speed: 200m/min	PSBNR2525-43
Feed: 0.25mm/rev	SNMG120408N-UZ
Dry method	

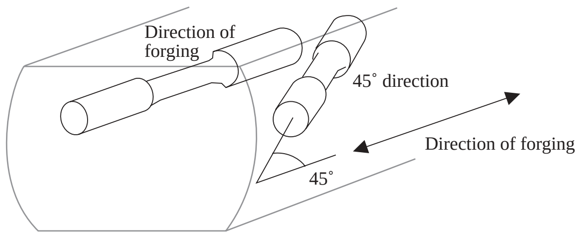


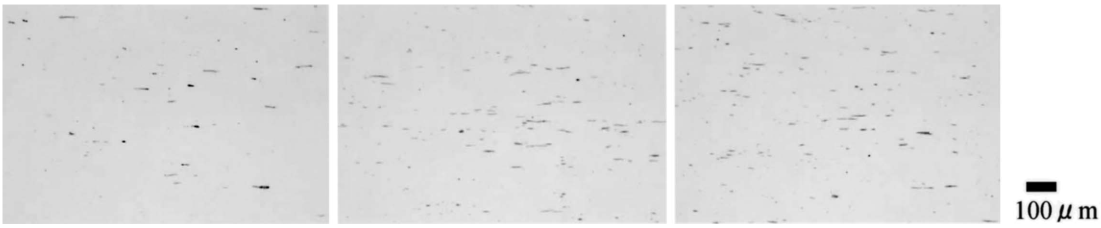
Fig. 2 How to cut out test pieces from the raw material

Furthermore, a tensile test was carried out as an index of mechanical properties. The tensile test was in accordance with JIS with 0.2% yield strength, tensile strength, elongation, and reduction in area established as evaluation items. Furthermore, Ono's rotating-bending fatigue test was carried out for evaluating fatigue strength. **Fig. 2** shows how to cut out a test piece from the raw material. A test piece was also cut out in 45˚ direction so that anisotropy against forging or rolling direction can be evaluated in this paper.

4. Experiment results

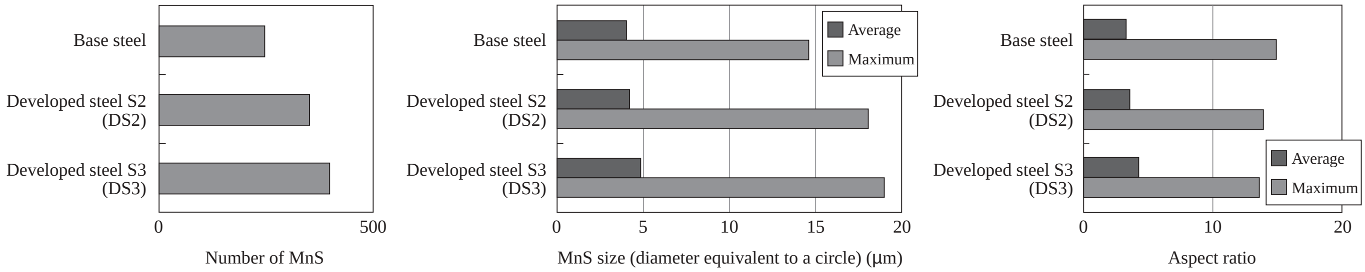
4.1 Evaluation of microstructure

Figs 3 and **4** respectively show the photos of MnS distribution and the quantitative measurements of MnS. MnS increased in number as S increased. The diameter equivalent to a circle slightly increased, but the aspect ratio remained almost unchanged. This tendency is assumed to vary according to the extent of deformation due to forging. However, despite an increase in S, almost all of the S was present as minute MnS in this developed steel. The influence is there-



(a) Base steel (b) Developed steel S2 (DS2) (C) Developed steel S3 (DS3)

Fig. 3 Distribution of MnS in the section in longitudinal direction of sample materials offered



(a) Number of MnS **(b) MnS size (diameter equivalent to a circle)** **(c) MnS aspect ratio**

Fig. 4 Results of measurement of the number and forms of MnS in steel

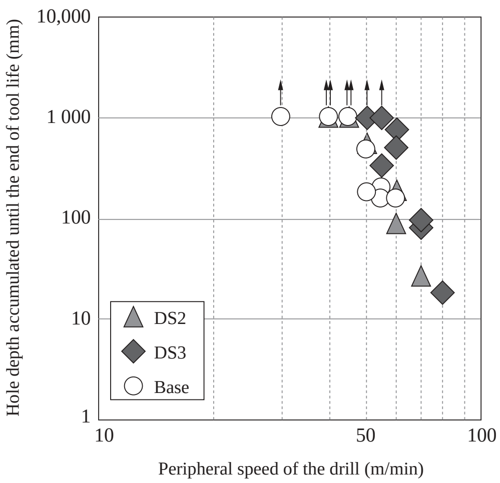
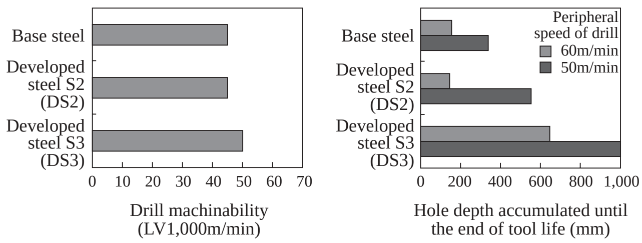
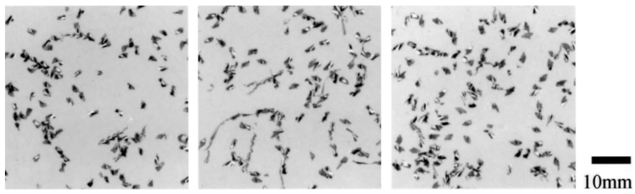


Fig. 5 Relationship between peripheral speed and accumulated hole depth



(a) Drill machinability VL 1000 **(b) Accumulated hole depth at each drilling speed**

Fig. 6 Results of evaluation of drill life



(a) Base steel **(b) Developed steel S2 (DS2)** **(c) Developed steel S3 (DS3)**

Fig. 7 Shapes of chips produced when drilling holes

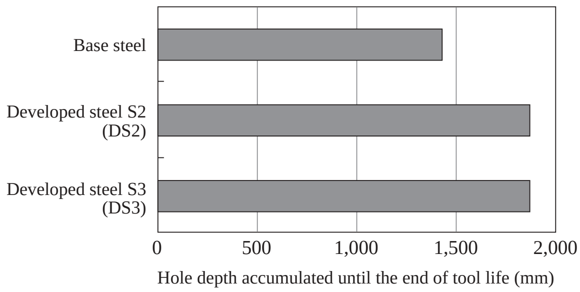


Fig. 8 Results of evaluation of drill life in deep hole drilling

fore considered small on mechanical properties and productivity.

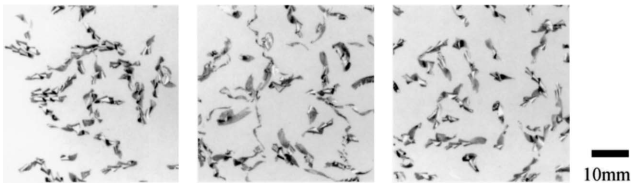
4.2 Drill Life

Fig. 5 compares the lives of drills in the ordinary drill test. The drills showed almost the same life in developed steel DS2 against the base steel, and a somewhat longer life in developed steel DS3. In addition, **Fig. 6** (a) and (b) show the detail. The speed at which a 1,000-mm-deep hole can be bored, VL1000, exceeded 50 m/min., with the highest speed found in developed steel DS3. A similar tendency was also observed in the depths of holes bored at 50 m/min and 60 m/min until the end of each tool life. The tool lasted longest in developed steel DS3.

Fig. 7 shows the forming of chips. The chips in developed steel DS2 were slightly longer than those generated from basic steel, and at the same level in developed steel DS3.

4.3 Results of deep hole drilling tests

Fig. 8 shows the drill lives in the deep hole drilling test. The



(a) Base steel (b) Developed steel S2 (DS2) (c) Developed steel S3 (DS3)

Fig. 9 Shapes of chips produced when drilling a deep hole

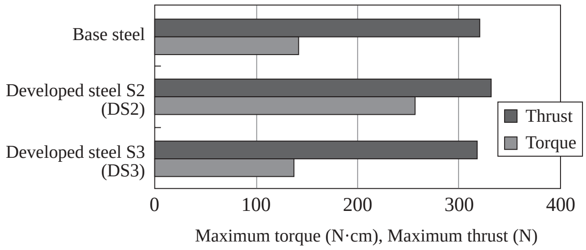


Fig. 10 Cutting forces when drilling a deep hole

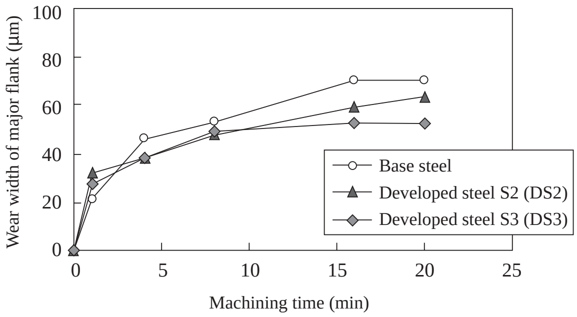
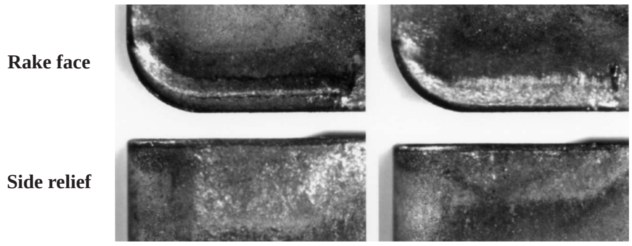
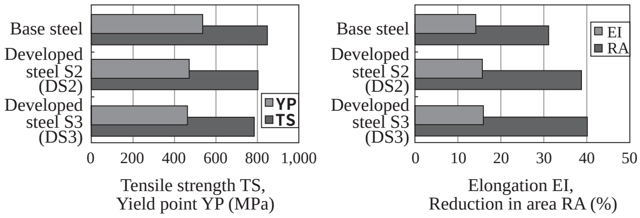


Fig. 11 Relationship between cutting time and the wear width of major flank when turning the peripheral



(a) Base steel (b) Developed steel S3 (DS3)

Fig. 12 Tool edge worn out



(a) Tensile strength TS, Yield point YP **(b) Elongation EL, Reduction in area RA**

Fig. 13 Various properties in tensile tests

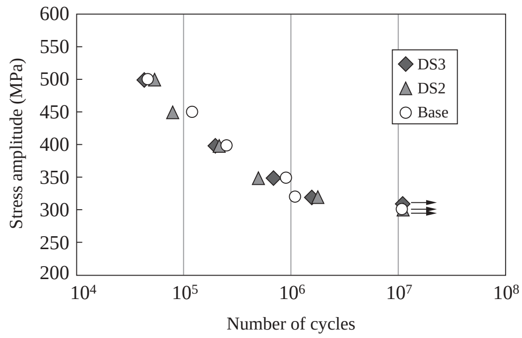


Fig. 14 Fatigue property of test pieces at 45˚ to forging direction

drills were found durable enough when boring deep holes in developed steel DS2 and DS3.

Fig. 9 shows how chips were observed. The chips of the base steel and developed steel DS3 looked similar while those of DS2 contained some slender stretching. The deep hole drilling test is greatly influenced by the machining conditions, and the results in question offer just an example. However, it is safe to say that a hole equal to or higher than that of the conventional material in depth can be bored under the nearly practicable conditions.

Fig. 10 shows a comparison of torque and thrust. Developed steel DS2 showed a tendency of slightly higher cutting forces than other test materials.

4.4 Results of turning tests

Fig. 11 shows the findings of measurement of the wear width in a major flank in the turning test. No significant difference was observed among the test materials in a machining time of some 20 minutes. **Fig. 12** shows the examples of the findings of observation of the tool wear. Both tools looked almost undamaged. In case of developed steel DS3, however, something looking like a protective nonmetallic layer (belag) can be observed on the rake face.

4.5 Tensile properties

Fig. 13 shows the tensile properties. The developed steel is almost equal to the base steel in yield point, tensile strength, and elongation, and higher than the latter in reduction in area.

4.6 Results of Ono's rotating-bending fatigue tests

Fig. 14 shows the S-N curves of the test pieces cut out at 45˚ in the length direction. Evaluation was made with 10^7 set as a fatigue limit. However, no significant difference was observed among all the test pieces. The properties of developed steel DS2 and DS3 were almost equal to those of the base steel.

5. Conclusion

The findings of the comparison of the machinability and basic mechanical properties between the free-machining micro alloyed steel (base steel), in which Pb is added to the micro-alloyed steel for crank shafts, and the lead-free free-machining steel (developed steel) can be summarized as follows:

(1) The number of MnS increases as the quantity of S to be added increases through the technique of dispersing pulverized MnS. The diameter equivalent to a circle slightly increased, but the aspect ratio remaind almost unchanged.

(2) Even the lead-free steel was considered machinable with the addition of S.

(3) The developed steel was almost equal to the base steel in yield

point, tensile strength, and elongation, and higher than the latter in drawing.

(4) In the fatigue test of the test piece cut out in 45˚ direction for evaluation of hardness, the developed steel in which MnS was increased in quantity was almost same with the base steel in properties. The influence of an increase in the quantity of S was not significant.

References

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