

@arsa`bs9

Free cutting steel consists of two types, one for machine structural use and the other based on low carbon steel for hard cutting, such as SAE 12L14. Conventionally, Pb has been added to free cutting steels to improve their machinability, but Pb in steel is thought to have a harmful effect on the human body. Therefore, as alternatives to Pb addition in free cutting steels, JFE Steel and NKK BARS & SHAPES studied graphite precipitation in the steel and control of the sulfide morphology by the chemical composition and developed new Pb-free free cutting steels based on these respective concepts. In the graphite-type free cutting steel for machine structural use, JFE Steel realized machinability equal to that of the Pb-added steel by controlling the state of existence of C in the steel, and achieved an excellent balance of cold workability and high fatigue strength after quenching and tempering. As a substitute for the low carbon Pb-added free cutting steel (SAE 12L14), NKK BARS & SHAPES developed a steel with improved machinability by utilizing large sulfide inclusions, which is realized by increasing S addition while also adding Cr on the basis of the estimation from the calculated phase diagrams.

## 1. Introduction

Free cutting steels with Pb addition are widely used as materials for automobile and industrial machinery parts. However, in recent years, the use of Pb has been considered a problem from the viewpoint of environ-

mental protection.

Free cutting steels can be broadly classified into two types, (1) a free cutting steel for machine structural use, in which cold forgeability and high strength, are required simultaneously with machinability, and (2) so-called low carbon free cutting steels, in which machinability with a low carbon composition is the primary requirement, as represented by SAE 12L14.

As alternatives to Pb addition for improving machinability, JFE Steel and NKK BARS & SHAPES developed free cutting steels by utilizing graphite precipitation in the steel and controlling the sulfide morphology by the chemical composition of the steel, corresponding to these respective applications. This paper introduces these steels.

## 2.

and cold forgeability without Pb addition to the steel has been desired.

Based on this background, a free cutting steel which possesses high fatigue strength and does not require Pb addition had been strongly desired. The key point for realizing a material with these features was to discover some means of improving machinability without reducing fatigue strength.

In this development, as an alternative to Pb addition and inclusion control by free cutting additives, control of the state of C existing in the steel was studied as a completely unprecedented factor for improving machinability. The most important feature of this development is that C which normally exists in steel in the form of cementite is changed to graphite. However, in steels for machine structural use, which have a hypoeutectoid composition, industrial use of graphite had been difficult with the conventional technology.

This chapter describes the chemical composition for enabling industrial graphite precipitation and its effect on the properties of steel for machine structural use.

## **2.2 Concept of Development**

### **2.2.1 Use of graphite to improve machinability-fatigue strength balance**

The concept of utilizing graphite in the developed steel is shown schematically in **Fig. 1**. Changing hard cementite to graphite makes it possible to soften the steel and thereby improves machinability. Machinability

is also substantially improved by the lubricating action of the graphite on the tool surface. On the other hand, because graphite particles are redissolved into the matrix

### **2.2.3 Increase in number of graphite nucleation sites utilizing BN**

Fine dispersion of graphite particles in steel is effective both for preventing deterioration of fatigue strength and for shortening the graphitization time. To achieve fine dispersion of graphite particles, it is necessary to increase the number of nucleation sites. In this development, acceleration of graphite nucleation by precipitates in the steel was studied. Although nucleation of graphite particles was accelerated by the existence of various types of precipitate in the steel, BN was an extremely effective nucleation site.<sup>3,4)</sup>

In addition to the crystallographic structure of the precipitates, graphite and BN also bear an extremely close resemblance in terms of their precipitation modes.

strength exceeding 500 MPa after quenching and tempering. In comparison with the size of the inclusions in the conventional free cutting steel, which is on the order of several 10s of micro meter, the graphite particles are fine, at several micro meter, due to the increase in the number of nucleation sites using BN. Furthermore, the graphite in the steel dissolves into the steel matrix due to heating during quenching. It should be noted that, although unsolved BN also exists in the developed steel, its size is about 1  $\mu\text{m}$ . Thus, because the graphite and BN used in the developed steel are both fine, unlike the conventional inclusions, they are thought to have no negative effect on fatigue strength.

The developed steel can be used in a wide range of applications in steel for machine structural use, centering on parts where the conventional Pb-added steel had been used and cold forging applications where machinability is a problem and high strength had been difficult to realize.

### 3.

containing 0.3% Pb and 0.3% S. In automotive applications, it is used in large quantities in transmission oil hydraulic control valves and oil hydraulic hose con-

ably high oxygen content, on the order of 150 ppm, it was considered difficult to improve its machinability by adding Ca or B, which is already used in the steel for machine structural use. Therefore, because it was necessary to conceive a different method, the authors studied S, which is added in large quantity as an element which improves machinability. It has long been known that the machinability of S-added free cutting steels is improved as the size of sulfide inclusions becomes larger.<sup>7)</sup> Therefore, the improvement of machinability by forming large sulfide inclusions was studied from this viewpoint. Because the construction of thermodynamic databases for sulfides has proceeded rapidly accompanying a progress in microalloying technology, this type of database was effectively used in this study.

For the developed steel, first, a phase diagram was obtained by the phase equilibrium calculation of a multi-component alloy system, and the alloy composition with which large sulfide inclusions could be expected was predicted. Based on the results, confirmation tests were actually conducted, including melting and machinability tests, to decide the alloy composition, and a new Pb-free free cutting steel was developed. The authors

wish to note that this new material was developed jointly with Prof. Kiyohito Ishida of Tohoku Univ. and Senior Researcher Katsunari Oikawa of AIST Tohoku: National Institute of Advanced Industrial Science and Technology.

## 3.2 Concept of Developed Steel

### 3.2.1 Prediction by phase diagram calculation

The sulfide inclusions which contribute to machinability are crystallized by a monotectic reaction during solidification of the molten steel.<sup>8)</sup> When considering the methods for securing large sulfide inclusions, the following methods are conceivable:

- (1) Crystallization of large sulfide inclusions in the solidification stage
- (2) Reduction of the forging ratio after crystallization

In case of (1), the reduction of solidification rate is a general method, and increasing the casting cross-sectional profile or slow cooling during casting is conceivable. However, in both methods, it is difficult to effect large changes in the current continuous casting process. On the other hand, in case of (2), if the production of rolling materials of the same size is considered, the reduction of forging ratio by using a smaller casting cross-sectional profile is conceivable. However, as mentioned previously, adoption of a small casting cross-sectional profile results in the reduction in the size of inclusion during casting, and thus would have little effect. The authors therefore believed that a composition system which expands the temperature range in which



oped steel.

As described above, the 1%Cr-0.4%S steel was adopted as the Pb-free free cutting steel as a result of confirmation tests with experimental melting furnace steel

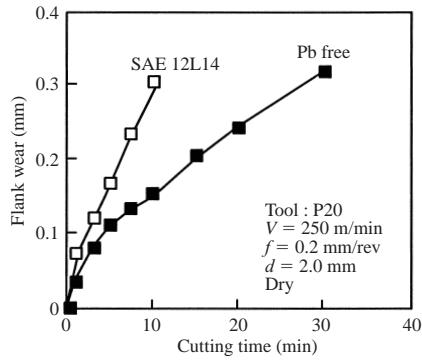


Figure 1: Flank wear (mm) versus cutting time (min) for SAE 12L14 and Pb free steel. Parameters: Tool: P20, V = 250 m/min, f = 0.2 mm/rev, d = 2.0 mm, Dry.

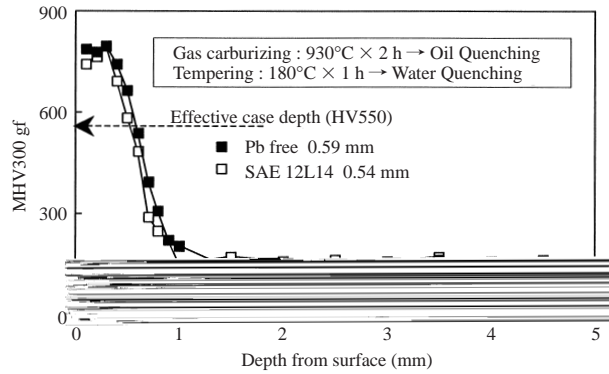


Figure 2: MHV300 gf versus depth from surface (mm) for SAE 12L14 and Pb free steel. Heat treatment: Gas carburizing: 930°C x 2 h -> Oil Quenching, Tempering: 180°C x 1 h -> Water Quenching. Effective case depth (HV550) is indicated.

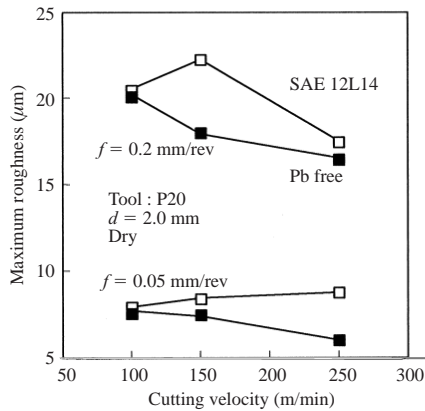


Figure 3: Maximum roughness (µm) versus cutting velocity (m/min) for SAE 12L14 and Pb free steel. Parameters: Tool: P20, d = 2.0 mm, Dry.

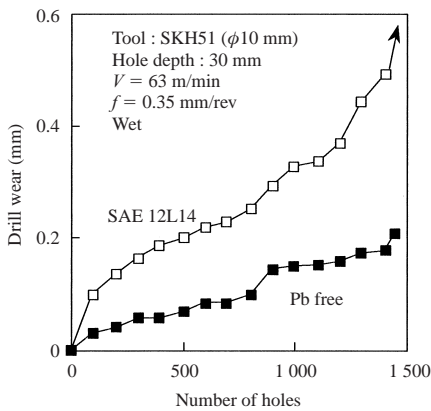


Figure 4: Drill wear (mm) versus number of holes for SAE 12L14 and Pb free steel. Parameters: Tool: SKH51 (φ10 mm), Hole depth: 30 mm, V = 63 m/min, f = 0.35 mm/rev, Wet.

#### 4. Conclusion

This paper has introduced two new Pb-free free cutting steels, a free cutting steel for machine structural use and a substitute for SAE 12L14, which were developed in response to customers' needs from the viewpoint of global environmental problems.

The graphite-precipitation type Pb-free free cutting steel for machine structural use contains no substances which are harmful to the environment and possesses excellent machinability and cold forgeability, amply sat-

isfying the property requirements of steel for machine structural use.

The SAE 12L14-substitute Pb-free free cutting steel features improved machinability by large sulfide inclusions. This was possible for the first time by adding Cr and further increasing the S content based on the estimation from the calculated phase diagrams.

With the increasing trend toward green procurement in all industries, there is a tendency to reduce the use of Pb. To meet this need, JFE Steel and its group companies will continue to develop new products to ensure that these Pb-free free cutting steels can be used in a variety of fields.

#### References

- 1) Iwamoto, T.; Hoshino, T.; Amano, K.; Nakano, Y. "An advanced high strength graphitized steel for machining and cold forging uses." 2nd Internat. Symp. on Microalloyed Bar & Forging Steel. Colorado, 1996, p. 277.
- 2) Yamanaka, N.; Kusaka, K. On the mechanism of graphitization of high-carbon steel. Tetsu-to-Hagané. vol. 48, 1962, p. 946.
- 3) Iwamoto, T.; Ota, H.; Hoshino, T.; Amano, K.; Shimomura, J. Graphite nucleation on boron nitride in 0.53%C Steel. Tetsu-to-Hagané. vol. 84, 1998, p. 67.
- 4) Iwamoto, T.; Hoshino, T.; Matsuzaki, A.; Amano, K. Effects of boron and nitrogen on graphitization and hardenability in 0.53%C steel. ISIJ Int. vol. 42, 2002, s77.
- 5) Ohno, T. 96th and 97th Nishiyama Memorial Seminar, ISIJ, Tokyo, 1984, p. 157.
- 6) Murakami, T.; Shiraga, T. Free cutting steel containing BN inclusions without lead addition. NKK Technical Report. no. 178, 2002, p. 21.
- 7) Van Vlack, L. H. Correlation of machinability with inclusion characteristics in resulfurized Bessemer steels. Trans. ASM. vol. 45, 1953, p. 741.
- 8) Oikawa, K.; Ohtani, H.; Ishida, K.; Nishizawa, T. Morphology control of MnS in steel during solidification. Tetsu-to-Hagané. vol. 80, 1994, p. 623.
- 9) Oikawa, K.; Mitsui, H.; Ishida, K. Thermodynamic database for Fe-S base multi-component alloy. CAMP-ISIJ. vol. 16, 2003, p. 1516.
- 10) Shiraga, T. Materials control through bar and wire rod rolling. CAMP-ISIJ. vol. 12, 1999, p. 961.
- 11) Murakami, T. The Special Steel. vol. 52, 2003, p. 22.