UDC 669 . 14 . 018 . 26

Properties of Graphitic Steel for Cold Forging

Makoto OKONOGI*1 Masayuki HASHIMURA*1
Hideo KANISAWA*1 Sakae KATAYAMA*1

Abstract

Steel that is used for strengthened parts in machines after forging and machining processes is higher in strength as the amount of carbon increases. However, its workability and machining are poor. This presents a problem for strengthening and processing properties to co-exist in a steel product. Because we maintained the carbon in steel as graphite that easily deforms and made a matrix as a ferrite that is close to pure iron, we developed graphitic steel that is soft and has superior processing properties despite having high carbon amounts. Also, because higher strength is accomplished by decomposing graphite and dissolving carbon into the matrix using heat treatment after processing, it is possible for both strength and processing properties to co-exist. Particularly, steel in which graphite has been minutely dispersed has good induction hardening characteristics.

1. Introduction

There are many cases in which steel for machine parts is formed to a prescribed shape by cold forging, drawing or machining before strengthening it by quenching to make a final product. For that reason, ensuring component strength in the final product and the formability during the forming process are required for the characteristics of the material quality.

Generally, as the amount of carbon content increases, the carbon changes into the form of cementite. Because cementite degrades formability, strength is given after forming the low carbon steel by carbo-quenching or it is softened by spheroidizing the cementite in the medium carbon steel and then strengthened through heat treatment after forming. However, in carbo-quenching, the heat treatment time is long, and steel that has more than 0.45 wt% of carbon content has problems such as decreased mold life because of insufficient softness with the spheroidizing. In order to handle these issues, carbon was precipitated in the form of an easily deformed graphite. Even high carbon steel was able to be softened to the level of a lower carbon steel. We dissolved graphite in the quenching process afterwards and dissolved it in a matrix to develop a graphitic steel that can be strengthened according to the added carbon amounts.

*1 Technical Development Bureau

2. Characteristics of Graphitic Steel

Graphitic steel has the microstructure of graphite separated from its ferrite phase. Fe-graphite is stable in the Fe-C phase diagram. But space to precipitate graphite needs to be ensured to allow graphitization. For that reason, it is necessary to diffuse Fe. Fe-graphite is difficult to form in normal hypo-eutectoid steel. In promoting the precipitation of graphite, alloy elements of Cr and Mn were reduced to stabilize the cementite in view of heat equilibrium and components that increase instability such as Si and Ni were used[1]. The means for promoting graphitization by making the microstructure of the former cementite fine were employed[2].

Because the formability of graphitic steels is superior, it is possible to greatly decrease the costs of cold forging and machining. **Fig. 1** shows the methods of use presumed for graphitic steel. Components that do not require strength can be used as they are and those components that must be strong can be strengthened through heat treatments to arrive at the final product.

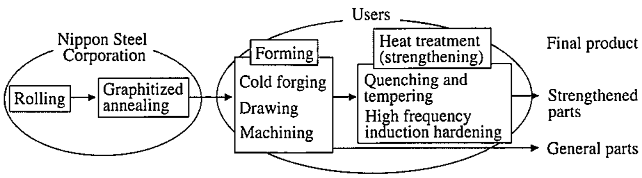


Fig. 1 Expected usage methods

3. Material Characteristics

3.1 Microstructure

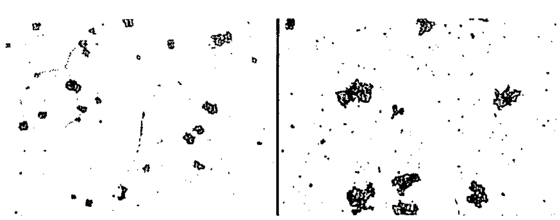
Specimens used for the characteristic evaluations has the compositions shown in **Table 1**. After rolling, graphitization was done in an annealing furnace. The size of the graphite particle depends strongly on heat treatment. Therefore, it is possible to separate the graphite particle size under these conditions. **Fig. 2** shows an example of the graphitic steel with different sized graphite particles. In the bar mill and wire rod mill of Muroran Works, it is possible to manufacture separately the graphitic steels with the fine and coarse particles that were clearly different in size by controlling the cooling that uses an on-line rapid cooling apparatus (called DSQ: Direct Surface Quench and EDC: Easy Drawing Conveyor). In either case, the matrix is ferrite and is in a state near pure iron.

3.2 Properties of the steel as graphitized

Fig. 3 shows tensile strength properties of graphitic steel of 0.55 wt% C and S55C–SA(Spheroidizing Annealing). Graphitic steel is approximately 130 MPa in tensile strength (TS) and approximately 90 MPa softness in yield strength (YP) compared to S55C-SA, and it is at the strength level of S15C. Therefore, even with a steel equivalent to S55C formed by either hot or warm forging methods, it is possible for softness to be at the strength level that can be cold forged. **Fig. 4** shows the relationships of the tool pressure at the die surface and the tool life. Based on the deformation resistance found in the cold upsetting tests, the surface pressure of the tool was calculated using FEM analysis and the tool life in the rearward extrusion was estimated. It can be expected that the tool life can be increased approximately 5 times compared to that of S45C SA steel.

Table 1 Composition of specimen (mass%)

C	Si	Mn	Graphite particle size
0.55	1.0	0.5	Variable



(a) Fine particles (b) Coarse particles

Fig. 2 An example of the graphitic steel with different sized graphite particles by the controlled cooling

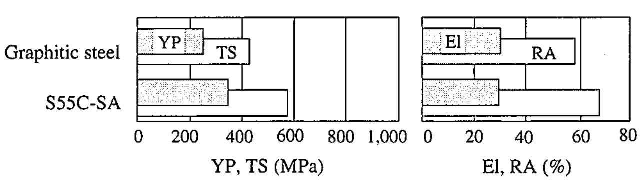


Fig. 3 Tensile strength of the steel as graphitized

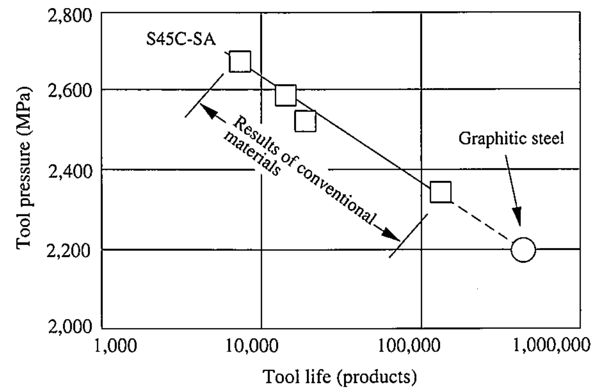


Fig. 4 Estimated tool life during rearward extrusion

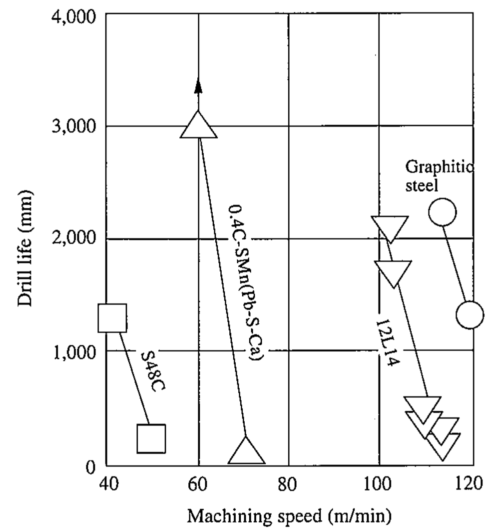


Fig. 5 Drill life for each free-cutting steel

Drill life was used as the index of machinability. **Fig. 5** shows the tool life of the drill made of high speed steel for various free-cutting steel[3]. The tool life of the graphitic steel was longer than that of the low carbon free-cutting steel, SAE 12L14 which is considered the most machinable.

The characteristic of the developed steel as graphitized is a duplex phase structure of ferrite and graphite which makes it superior for cold forging and for tool life while machining, and good for forming.

3.3 Properties of post-strengthening steel

After graphitization, strengthening was attained through quenching and tempering (QT) and the characteristics of that steel was investigated. **Fig. 6** shows the tensile strength of 0.55 wt% C graphitic steel and S55C after quenching and tempering (QT). Graphitic steel was reduced in elongation (El) and reduction (RA) after QT and the tensile strength and yield strength were substantially the same as S55C–QT. **Fig. 7** shows the Ono type rotating bending fatigue properties. Its fatigue properties were substantially the same as S55C–QT.

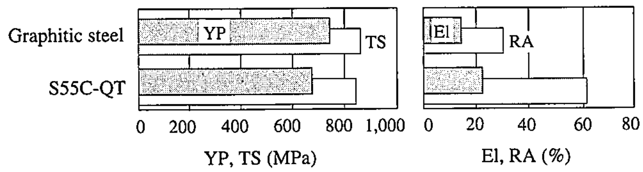


Fig. 6 Tensile strength after strengthening

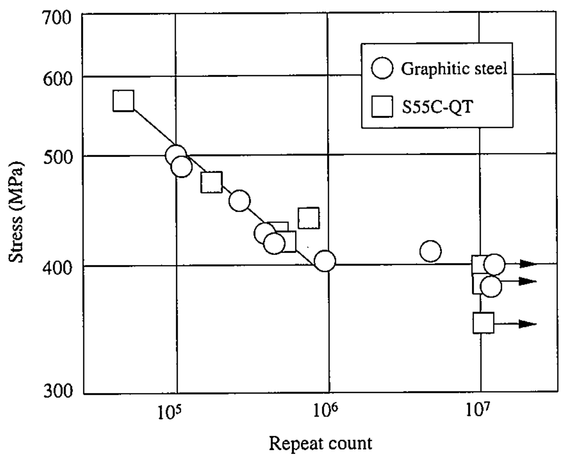


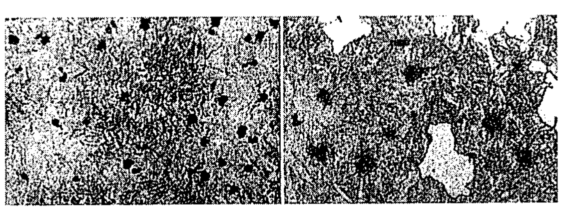
Fig. 7 Rotating bending fatigue characteristics

In this way after strengthening, the steel properties, with a level substantially the same as that of QT steel, the same amount of carbon was ensured.

3.4 Properties of high frequency induction hardening

Because the distance between graphite particles was large compared to the distance between cementite particles in spheroidized steel, coarse particles of the graphite were structured with a combination of martensite and ferrite. They did not achieve a uniform hardness without complete carbon diffusion because there were only several seconds for heat holding time in austenite during high frequency induction hardening.

The influence of graphite particles affecting the structure through high frequency induction hardening with the holding time of 3 seconds is shown in **Fig. 8**. The microstructure is martensite and ferrite when graphite particles were coarse, but the carbon diffused substantially uniformly for fine particles and it had a single phase microstructure of the martensite. **Fig. 9** shows the hardness distribution when the holding time was varied. There are great variations in hardness because the microstructure consists of martensite and ferrite when the holding time was less than 30 seconds for coarse particle graphite. But with finer graphite particles, attaining a substantially uniform hardness distribution was possible.



(a) Fine particles (b) Coarse particles

Fig. 8 Microstructure after high frequency induction hardening

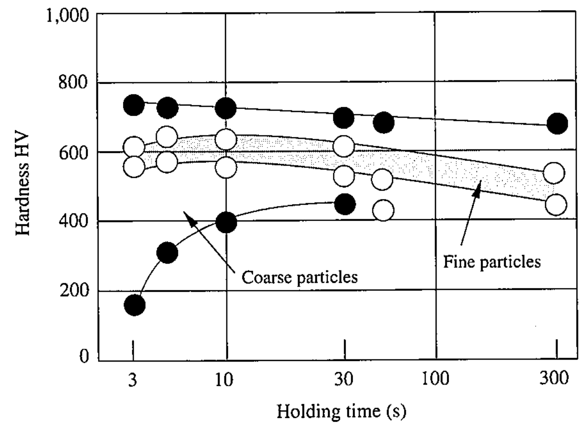


Fig. 9 Relationships of heat holding time and hardness distribution

4. Conclusion

The developed graphitic steel has superior cold forging and machining properties as it is when it has been graphitized. After heat treatment, it is possible to get higher strength with the level substantially equivalent to spheroidized steel that has the same amount of carbon to allow for both formability and high strength. Also, graphitic steel that has fine graphite particles dispersed through on-line controlled cooling was confirmed to easily allow high frequency hardening strengthen.

References

1) Kawano, Y., Inoyama, N., Kurai, K.:The Journal of the Japan Foundrymen's Society. 45, 17(1973)
2) Sueyoshi, H., Suenaga, K.:J. Japan Inst. Metal. 42, 676(1978)
3) Katayama, S., Toda, M.:Journal of Material Processing Technology. 62, 358(1996)