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Heat treatment effects to the fracture splitting parameters of C70S6 connecting rod

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1. Introduction

The fracture splitting method is an innovative processing technique in the field of the automobile engine connecting rod (con/rod) manufacturing. Compared with traditional method, the technique has remarkable advantages. It can decrease manufacturing procedures, reduce equipment and tools investment and save energy. Hence the total production cost is greatly reduced. Furthermore, the technique can also improve product quality and bearing capability [1]. It provides a high quality, high accuracy and low cost route for producing connecting rods (con/rods). Sawing and machining processes of the rod and cap, in order to mate two faces can be eliminated, and is believed to reduce the production cost by 25%. Another advantage of this production method is that fracture-splitting connecting rods exhibit 30% higher fatigue strength and 13% less weight than conventional connecting rods, and can be splitted into two pieces (big body and cap) by fracturing with an instant impact load. Compared with powder metal and cast con-rods, it also has lower cost for the whole manufacturing process. Hence, it provides more advantageous production opportunities, and is prefered in manufacturing technology mostly [2].

1.1. Purpose and the content of the study

One of the fracture parameters optimizing methods is to change the microstructure without tampering the chemical structure by heat treatment applications. The fracture capability and effect of microstructure after austempering, optimizing the fracture parameters and comparing the conventional pearlitic C70S6 (produced in compliance with DIN 17100 and inspected according to EN 10204) and bainitic C70S6 have been investigated in this study. Bainite is an important microstructure between martensite and pearlite. It is neither hard as martensite nor soft as pearlite. Because of this, it is noteworthy for academic study to examine especially upper bainite usability as main structure for crackable connecting rods. No reference or research has been met about changing the microstructure of crackable C70S6 con-rod steel by heat tretment methods in literature. The author and his colleagues have studied and made experiments on martensite and tempered martensite [3]. As known, bainite is an important microstructure due to its outstanding mechanical properties. That is because, it has been especially emphasized on bainite. In detail, for crackable connecting rods as far as strength is desired but also toughness is not much allowed for fracture splitting property, theoretically upper bainite could be a perfect choice for crackable connecting rods, also there is no technological use of bainite in crackable connecting rods. The author has proved perfect fracture for upper bainite in his Ph.D. thesis [4]. The parameters for perfect fracture is explained in detail at chapter 2.2. These are the reasons why this study is an original one.

The study consists of austempering, fracture test, metallographic observation and the interpretation of these analysis. The hardness has been measured, the relation of the hardness and microstructure to the impact fracture load has been examined.

1.2. Brief knowledge about bainitic structure

In addition to pearlite, other microconstituents that are products of the austenitic bainite transformation exist; one of these is called bainite.

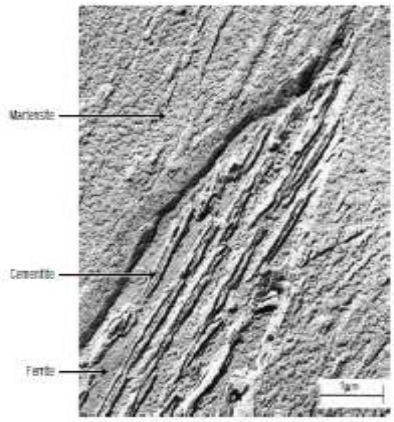

Fig. 1 Transmission electron micrograph showing the structure of bainite. A grain of bainite passes from lower left to upper right-hand corners, which consists of elongated and needle-shaped particles of Fe_3C within a ferrite matrix. The phase surrounding the bainite is martensite [5]

The microstructure of bainite consists of ferrite and cementite phases, and thus diffusional processes are involved in its formation. Bainite forms as needles or plates, depending on the temperature of the transformation; the microstructural details of bainite are so fine that their resolution is possible only using electron microscopy. Fig. 1 is an electron microscope that shows a grain of bainite (positioned diagonally from lower left to upper right); it is composed of a ferrite matrix and elongated particles of Fe_3C; the various phases in this micrograph have been labeled. In addition, the phase that surrounds the needle is martensite, the topic to which a subsequent section is addressed.

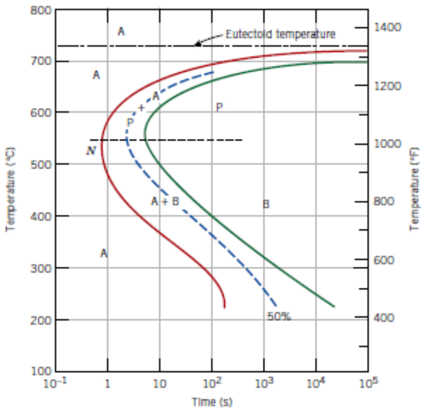

Fig. 2 Isothermal transformation diagram for an iron–carbon alloy of eutectoid composition, including austenite-to-pearlite (A–P) and austenite-to bainite (A–B) transformations [5]

Furthermore, no proeutectoid phase forms with bainite. The time–temperature dependence of the bainite transformation may also be represented on the isothermal transformation diagram. It occurs at temperatures below those at which pearlite forms; begin, end and half-reaction curves are just extensions of those for the pearlitic transformation, as shown in Fig. 2, the isothermal transformation diagram for an iron–carbon alloy of eutectoid composition that has been extended to lower temperatures. All three curves are C-shaped and have a "nose" at point *N*, where the rate of transformation is a maximum. As may be noted, whereas pearlite forms above the nose i.e. over the temperature range of about 540 to 727°C; at temperatures between about 215 and 540°C, bainite is the transformation product. It should also be noted that pearlitic and bainitic transformations are really competitive with each other, and once some portion of an alloy has transformed to either pearlite or bainite, transformation to the other microconstituent is not possible without reheating to form austenite.

1.3. Findings in literature and previous studies

Although C70S6 is excellent in fracture-splitability thanks to its small deformation during splitting, it has a coarser structure than the ferrite/pearlite structure of the medium-carbon micro-alloyed steels currently used as connecting rod steels. It is therefore low in yield ratio (yield strength/tensile strength) and cannot be applied to high-strength con-rods requiring high yield strength. Moreover, the inferior machinability of C70S6 owing to its pearlite structure has kept the steel from finding extensive utilization.

Because of the problems above, new studies for optimizing the fracture parameters have been carrying out. Steels for fracture-split components have been developed in response to the foregoing needs. The effect of martensite and tempered martensite to the fracture parameters have been studied in detail recently [3]. The research of fracture split of steel was carried out after changing the chemical structure: adding new elements as zirconium, calcium, aliminium [2] and titanium via finite elements method [6] recently.

The fracture parameters and microstructures have been examined by author and his colleagues in detail recently [7, 8]. Liming, Z. et al. investigated the lazer effect to the starting notch and fracture parameters [9]. Deen, Z. et al. investigated the lazer effect to the starting notch depth and Radius [10]. Roman C. et al. examined the fractured surfaces of connecting rods [11]. Kou S.Q. et al. composed the starting notch with laser and investigated the effect of this to the fracture parameters [12]. Iwazaki S. et al. designed and created a machine to manufacture crackable connecting rods [13]. Guirgos S. tried a different kind of method. In this method, crackable connecting rod's stress in the fracture area increases in a controlled atmosphere by a stress-increasing device and as the stress increases, the sudden fracture occurs [14].

1.4. Heat treatments effect to the microstructure evalution

In this article it is aimed to observe the mechanical behaviour of the fracture and the properties of the microstructure after austempering. It is aimed to understand the effect of austempering to the sudden (instant impact force) fracture. The metallography of the fracture surfaces have shown us some typical microstructures of bainite.

2. Examination

The examination consists of heat treatment application (austempering), fracture experiments, metallographic observation and the interpretation of these analysis. The hardness has been measured, the relation of the hardness and microstructure has been examined. Fractured specimens' optical photos were carefully examined at the Nikon MA 100 Metal Microscope.

2.1. Austempering

Austempering is applied to two C70S6 crackable con-rod steels as shown in Fig. 3. A technical drawing of C70S6 steel is shown in Fig. 4. Two C70S6 crackable connecting rods have been applied austenitizing 800°C for 1 hour in the controlled heat treatment furnaces separately and soonly after it was taken to salt bath in 450°C for 3 hours, then quenched in still air as shown in Fig. 5.

Table 1

Chemical composition of C70S6 steel, %

C	Si	Mn	P	Al	Cu	Cr
0.692	0.182	0.507	0.02	0.005	0.15	0.13
Ni	Mo	W	S	Sn	V	Fe
0.06	0.015	0.001	0.06	0.005	0.05	Bal.

Fig. 3 Austempered C70S6 crackable con rod

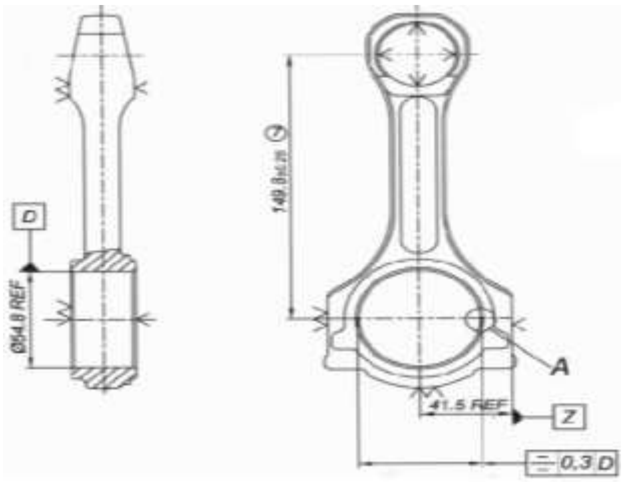

Fig. 4 C70S6 crackable con rod drawing

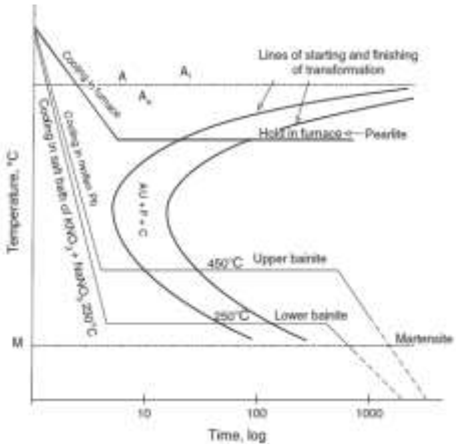

Fig. 5 Isothermal transformation diagram for C70S6 steel [15]

2.2. Fracture tests

The testing apparatus for evaluating fracture-splitability consisted of a split die and a 100 ton hydrolic press. The fracture has been started from starting notches (Fig. 6). The split die had the shape of a cylinder formed on a rectangular steel member. A wedge hole was machined in the mating faces of the two semicylinders. In the fracture-split test, the test piece was clamped in the split die, a wedge was inserted, and the assembly was placed on the hydrolic pressure. In these examples, fracture-splitting was conducted by 100 ton hydrolic press 150 mm. with an impact load (Figs. 7-9).

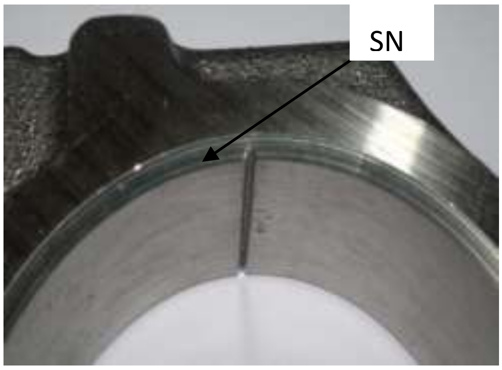

Fig. 6 Starting-Notch (SN) of crackable con-rod C70S6

Fig. 7 C70S6 con-rod before fracture test

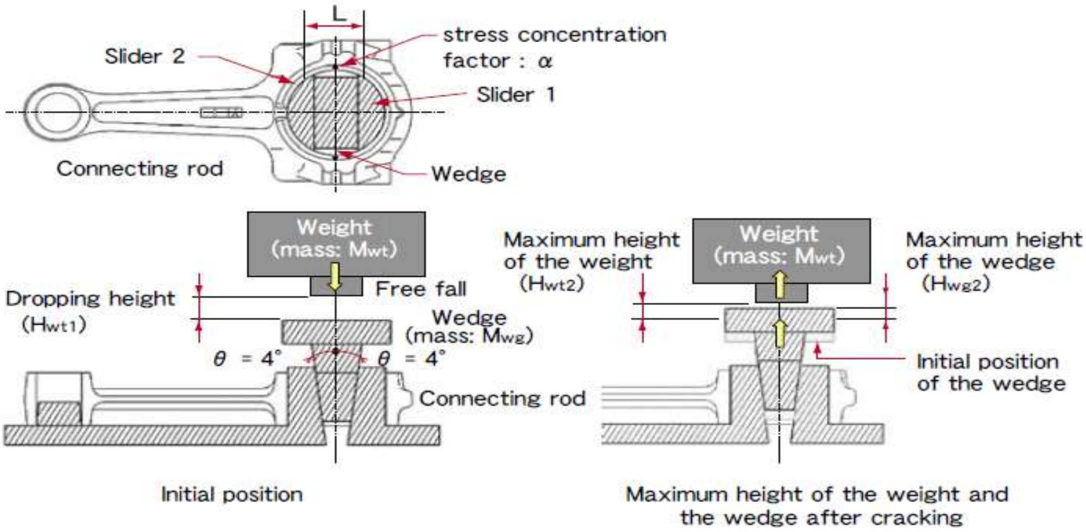

Fig. 8 A schematic view for fracture splitting process [8]

The fracture tests have been executed con-rods separately and a perfect brittle fracture has been obtained. Perfect fracture has to ensure some parameters; these are:

1. No material loss during fracture in two pieces (cap and rod).
2. No elastic deformation in fracture surfaces.

3. Exact match of the two surfaces after fracture so as to ensure the rough cleavage surfaces ensure the perfect match of cap and rod and have larger joint surface area than conventional machined smooth surfaces, so the processing accuracy, product quality and bearing capability are dramatically improved.

Fig. 9 Fracture experiments conducted

Fig. 10 Fracture surface after splitting

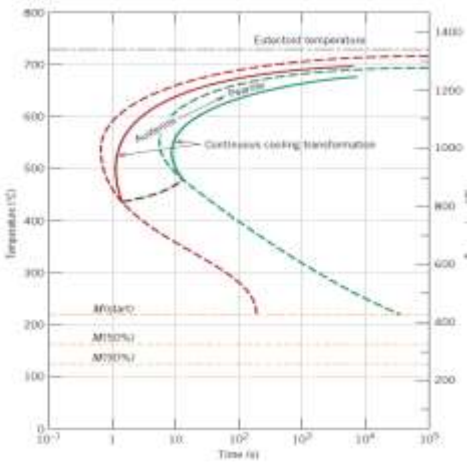

Fig. 11 Continuous cooling transformation diagram for eutectoid iron - carbon alloy [3]

As seen from Fig. 11, in 450°C the austenite transforms to upper bainite. It was chosen upper bainite transformation temperature (450°C), because the cementite particles here are thin (not very thin) enough to obtain brittle fracture without elastic or plastic deformation and enough toughness. This formation has been obtained due to the austempering by heat treatment process. The structure is neither too hard as martensite nor too soft as pearlite. It is considered that upper bainitic structure is to be an ideal form for crackable con-rods. These remarks are going to be explained in optical - SEM microstructures.

Lower bainite could be another research area. Lower bainite is not considered for crackable con-rod use due to its very thin cementite structure, because it is too elastic and tough, so brittle fracture could not be obtained.

The first line con-rod hardness value is 278 HB approximately and the other one is 306 HB. These values are desired results for fracture parameters.

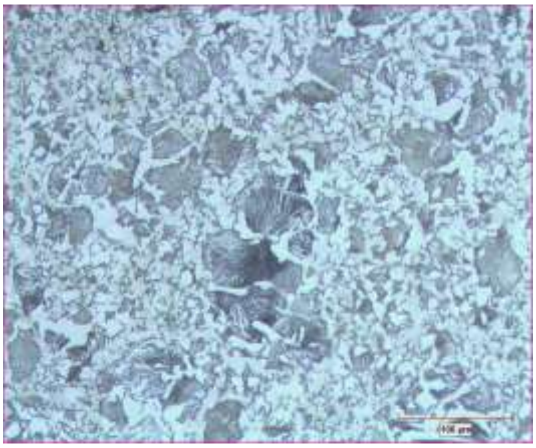

Fig. 12 Bainite in ferritic matrix (X 200)

The austempering has been applied to the sample before fracture splitting tests. The sample was prepared with 2% picric acid. Untransformed ferrite and bainite could be seen appearently (Figs.12 and 13).

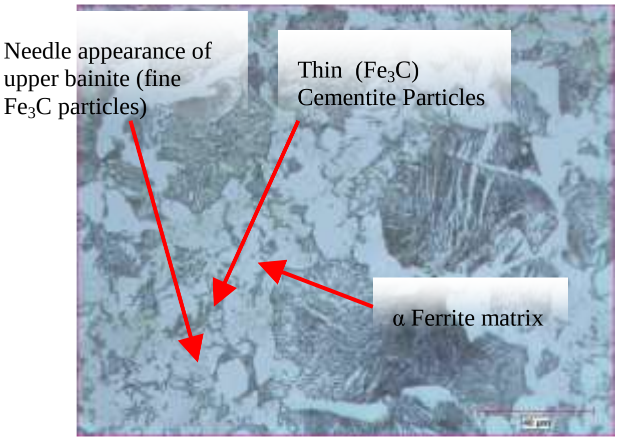

Fig. 13 Bainite in ferritic matrix (X 2000)

2.3. SEM analysis of bainitic microstructure

SEM analysis has been conducted with SEM LEO Gemini Electron Microscope FEI/QUANTA 400 FEG (25 kV) device.

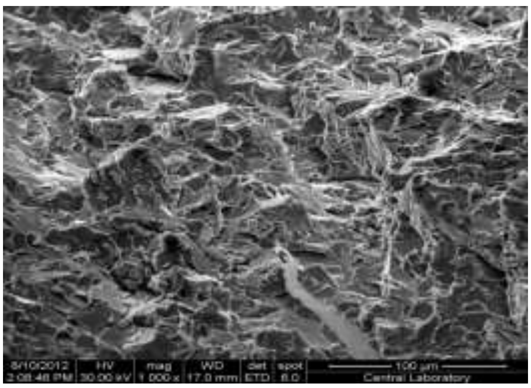

Fig. 14 SEM photo of bainite in ferritic matrix-1 (X1000)

A perfect brittle fracture could be observed in Fig. 14. It could also be seen granular and cleavage fracture in the fracture surface.

Microstructure transforms from austenite to upper bainite. Feathery appearence of bainite could also be seen clearly (Fig. 15).

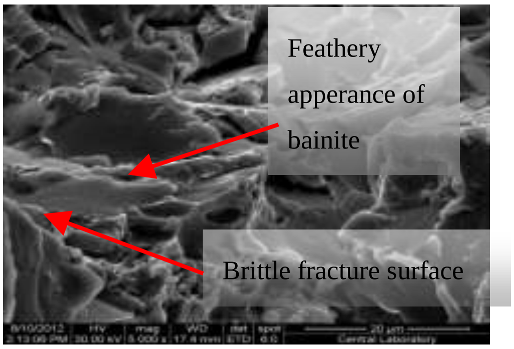

Fig. 15 SEM photo of bainite in ferritic matrix-2 (X5000)

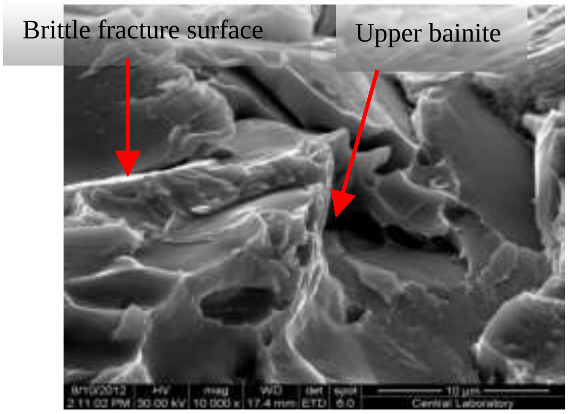

Fig. 16 SEM photo of bainite in ferritic matrix-3 (X10000)

The surface is a typical brittle and cleavage fracture surface (Figs. 15 and 16). Feathery bainitic appearence and Fe_3C particles could be seen appearently. Microstructure is a typical upper bainite. Upper bainite: there are carbide particles in present inside lower bainitic ferrite, since it forms in lower temperatures, no layer form occurs. It has same chemical composition as pearlite but harder than it. It is a cleavage and brittle fracture in splitting surfaces just as desired in fracture splitting process. Feathery apperance of upper bainite is obvious.

3. Conclusion

1. No material loss due to the perfect fracture was observed during the fracture tests.

2. SEM and optical microscopy analysis clearly disclose upper bainite.

3. Perfect brittle fracture surfaces shows a typical cleavage fracture necessary for crackable con-rods so as to ensure perfect match of cap and rod and have larger joint surface area than conventional machined smooth surfaces

4. Hardness values (278 and 306 HB) is nearly same as conventional pearlitic structure used in crackable con-rods.

4. Discussion

Upper bainitic microstructure could be an important alternative to the pearlitic microstructure because of perfect brittle fracture, no material loss and much more tough without sacrificing the brittleness. Bainite is important because it can be thought as a mixture of martensite (too hard) and pearlite (tough). The sole disadvantage may be economic production. This could be overcome with the growing and developing technology in austempering. Bainite could also absorbe impact forces, this is another advantage. Untransformed ferrite decreases the hardness a little, this lessens the brittleness a little and increases the toughness. No additional tempering is necessary for bainite, this is important for cost.

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C70S6 ŠVAISTIKLIŲ TERMINIO APDIRBIMO ĮTAKA SKILIMO SKLIDIMO PARAMETRAMS

Z. Özdemir

R e z i u m ė

Perskeliami švaistikliai buvo plačiai naudojamos automobilių varikliuose. Šiame metode nereikia mechaninio apdirbimo padalijant švaistiklį į dvi dalis. Perskeliamo C70S6 plieno mikrostruktūra yra perlitas (90% struktūros yra perlitas). Mikrostruktūros keitimas įvairiais terminiais apdirbimais gali būti ekonomiškos ir technologiškos alternatyvos C70S6 plieno panaudojimui. Šioje studijoje analizuojamas C70S6 plieno beinitinės mikrostruktūros poveikis. Austenitinis grūdinimas buvo panaudotas perskeliamam C70S6 plienui ir atlikti laužimo eksperimentai. Buvo stebimas puikus lūžio paviršius. Išmatuotas lūžio paviršiaus kietumas. Optinė ir SEM analizė patvirtino puikią paviršiaus beinitinę mikrostruktūrą. Buvo prieita išvada, kad beinitinė mikrostruktūra gali būti gera alternatyva tradiciniam perlitiniam perskeliamam C70S6 švaistikliui.

Z. Özdemir

HEAT TREATMENT EFFECTS TO THE FRACTURE SPLITTING PARAMETERS OF C70S6 CONNECTING ROD

S u m m a r y

Crackable connecting rods have been widely used in cars’ engines recently. In this method no machining is needed to seperate the connecting rod into two pieces. The main microstructure of the crackable C70S6 steel is pearlite (%90 of the structure is about pearlite). Changing the microstructure by various heat treatment applications can be economic and technologic alternatives to the use of crackable C70S6 steel. In this study, the effect of the bainitic microstructure of the crackable C70S6 steel is examined. Austempering has been applied to the crackable C70S6 steel and then fracture experiments has been carried out. It has been observed a perfect fracture surface. The hardness value of the fracture surface has been measured. Optical and SEM observations have showed us a perfect upper bainitic microstructure. It has been concluded that bainitic microstructure can be an important alternative to the convensional pearlitic crackable C70S6 connecting rods.

Keywords: bainitic microstructure, crackable connecting rod, heat treatment, metallographic examination, C70S6 steel.

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