Proceedings of the ASPF 2003 (The 8th Asian Symposium on Precision Forging), October 15 - 18, 2003

Strength Evaluation of Aluminum Alloy Bolt by Nano-Indentation Hardness Test

Yoshihiro KUBOTA[1], Tamotsu NAKAMURA[2],
Mitsuo KOBAYASHI[3], Katsumi FUKUDA[4],

[1]*Daiichi Kogyo Co., LTD, Hamamatsu, Shizuoka, 431-3112, JAPAN*
[2]*Shizuoka University, Hamamatsu, Shizuoka, 432-8561, JAPAN*
[3]*Kogakuin University, Hachiohji, Tokyo, 192-0015, JAPAN*
[4] *University of Tokyo, Bunkyou-ku, Tokyo, 113-8656, JAPAN*

Abstract

A high strength aluminum alloy bolt (A7050, T7 temper treatment) has been developed by the authors. The bolt has a small grain size in the whole area of the bolt because of the large equivalent strain followed by thermo-mechanical treatment. As the bolt made of A7050 has a risk of stress corrosion cracking, each grain should be strengthened the grain inside than the grain boundary in order to improve the stress corrosion cracking resistance. It has been confirmed that the nano-indentation hardness at each grain inside increased with the increasing equivalent strain by thermo-mechanical treatment processing.

Key word: Bolt, Cold forging, Aging, Grain size, Stress Corrosion Cracking

1. Introduction

Aluminum alloy bolts are used to join two or more aluminum frames. Such aluminum alloy bolts are required high strength. A high strength aluminum alloy bolt (A7050 alloy, T7 temper treatment) has been developed by the authors. The bolt has a small grain size in the whole area of the bolt because of the large equivalent strain followed by thermo-mechanical treatment. Moreover, the ductility and the stress corrosion cracking resistance have been improved by an over aging treatment, namely T73 temper treatment.

In the present paper, the distribution of nano-indentation hardness of microscopic area such as a thread portion where the bolt strength is required has been measured by a nano-indentation hardness tester.

On the other hand, the bolt made from A7050 alloy has the highest strength among aluminum alloy. However, 7000 series alloy has a risk of stress corrosion cracking. The crack mainly grows through the grain boundary. The mechanism of stress corrosion cracking will be due to hydrogen embrittlement. Therefore, the strength of grain boundary will influence on the stress corrosion cracking too. Moreover, it will be important to strengthen the grain inside relatively. So, the nano-indentation hardness in the grain inside with different grain size was measured by the nano-indentation hardness tester.

2. Experimental methods and conditions

2.1 Nano-indentation hardness tester

Nano-indentation hardness tester ENT1000 made in ERIONIKUS was used in the present paper. The resolution of displacement is 0.3 nm. The lording weight is very light 500 mgf. The impression size will be 0.1~1μm in the present test conditions.

2.2 High strength aluminum alloy bolt specimen

The dimension of this bolt is M10×L28. The hardness is about 180HV, the tensile strength is 540 MPa, and the total elongation is 7 %. As almost of the grains in the bolt were recrystallized by a solution heat treatment, the work hardening effect will be canceled.

Figure 1 shows the details of the thread portion of the bolt. The direction A and B indicated by arrows show the measuring directions. Each measuring point is at 50μm beneath the surface. The measuring surface of the hardness is mirror-finished by buffing to improve the accuracy of hardness measurement.

2.3 A7050 alloy cylindrical specimen for upsetting

The cold-upsetting test of the A7050 alloy cylindrical specimens has been carried out in order to examine the influence of the plastic strain by cold-forging. The series of the upsetting was conducted by use a lubricant of PTFE. The good uniaxial stress condition has been kept. The cylindrical specimens were hardened by T6 temper treatment. The nano-indentation hardness HN was measured at the each different size grain inside of near center portion in the cross section. The hardness HN is measured 5 times for each specimen.

2.4 A7050 billet specimen for ECAP

The equal-channel angular pressing (ECAP) has been carried out in order to examine the influence of the very large plastic strain for the precipitation hardening. ECAP is a processing procedure which can be accumulated a very intense plastic strain by iteration pressing of a same billet specimen through a special die as shown in Fig.2. If the crossed axes angle of the two channels in the ECAP die is 90(deg), the plastic strain of the billet specimen accumulated by one pressing will be approximately unity. The each billet specimen pressed from 1 to 4 times were hardened through the T6 temper treatment too. The measuring points and measuring condition of the hardness HN are same as the upsetting.

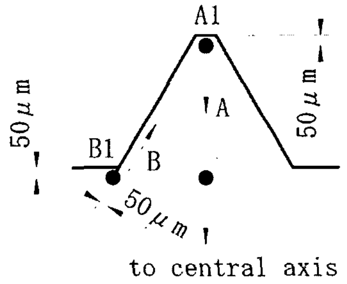

Fig.1 Measuring points in thread portion

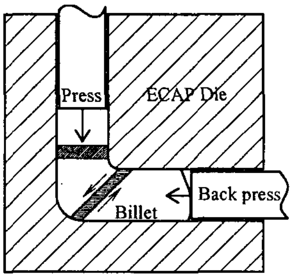

Fig.2 Schematic diagram of ECAP die

3. Experimental results and Discussion

Figure 3 shows the distribution of nano-indentation hardness HN measured in the A direction from the top of the thread A1 in **Fig. 1**. The thread portion is in the range within D=0~1mm and the shank portion is over D=1mm. The average of hardness HN_{ave}=203.5 in the thread portion is a little higher than hardness HN_{ave} =200.6 at the shank portion. Furthermore, the hardness HN has been decreased approximately with distance from the point A1 which is the top of the thread increases.

Figure 4 shows the distribution of the equivalent strain at the thread portion calculated by FEM simulation and the microstructure. The equivalent strain ϵ_{eq} increases from the central axis in the bolt toward the top of the thread. There is a little linear relationship between the hardness HN and the equivalent strain ϵ_{eq} in the microscopic area such as thread portion.

Therefore, the hardness HN inside grain is influenced by the equivalent strain in the cold forging and the thermo-mechanical treatment.

Figure 5 shows the distribution of the hardness HN measured in the B direction from the root of the thread B1. The average hardness HN is HN_{ave} =208.0. The hardness HN near the surface of the thread is a little higher than the inside portion of it. Therefore, the larger deformation is at a thread rolling, the harder a grain inside is.

Figure 6 shows the relationship between the hardness HN and average grain size d in case of the upsetting for cylindrical specimens. The each vertical line in this figure shows the average and the standard deviation. The hardness HN is decreasing approximately with the increase in average grain size d. This is because the grain size of the A7050 alloy decreases with the increase in the equivalent strain ϵ_{eq} for the thermo-mechanical treatment. Therefore, the hardness HN increases approximately with the increase in the equivalent strain ϵ_{eq}, even though the hardness HN once decreases when the equivalent strain ϵ_{eq} is 0.7 as shown in Fig.7. This increasing tendency is the same as the case of the bolt. It has been confirmed that the grain inside will be strengthened by enhanced precipitation hardness when large equivalent strain ϵ_{eq} can be given.

Figure 8 shows the relationship between the hardness HN and average grain size d in case of the billet specimens for ECAP. The series of numbers in this figure shows the pressing times of ECAP. Since the microstructure was presenting the mixed microstructure of a fine grain and a coarsening grain as shown in Fig.9. Therefore, the hardness HN of the each size grain inside was measured by dividing into two in the same specimen. The circle marks ○ in this figure shows the hardness HN values of the grain inside smaller than 10 μm, another square marks □ shows the one larger than 10 μm. The hardness HN in the grains smaller than 10 μm was clearly harder than the grains larger than 10 μm. In the range of very large plastic strain, although the hardness HN in the grains lager than 10 μm decreases with the increasing the average grain size d, the correlation is not accepted as for another grains smaller than 10 μm.

On the other hands, the both hardness HN also increases approximately with the increasing of equivalent strain ϵ_{eq} in the area of very large strain as shown in Fig.10.

5. Conclusion

1) The hardness HN of the thread portion was harder than the shank portion because the hardness of grain inside increases with the increasing of the equivalent strain.

2) The hardness HN of grain inside by the upsetting increases with the decreasing of the grain size, and increases linearly with the increase of the equivalent strain.

3) The hardness HN of grain inside by ECAP increases with the increasing of the equivalent strain. However, amount of the deformation is different locally in the thread portion or the ECAP. So, the local area with large equivalent strain will have a fine grains, the grain inside will be strengthen by enhanced precipitation hardening with the large equivalent strain ϵ_{eq}.

4) The equivalent strain by cold forging will strengthen the grain inside with a fine grain in the thermo-mechanical treatment. The stress corrosion cracking will be able to improved since stress concentration to the grain boundary is reduced relatively if the grain inside is strengthened.

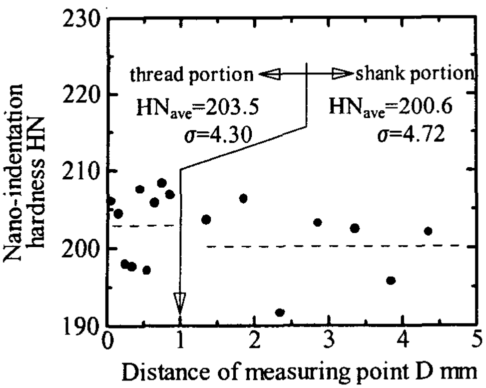

Fig.3 Hardness HN distribution in A direction

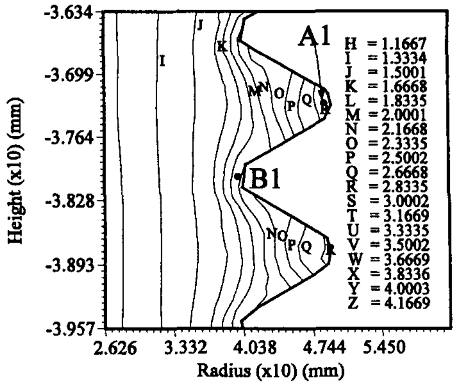

Fig.4 Distribution of equivalent strain

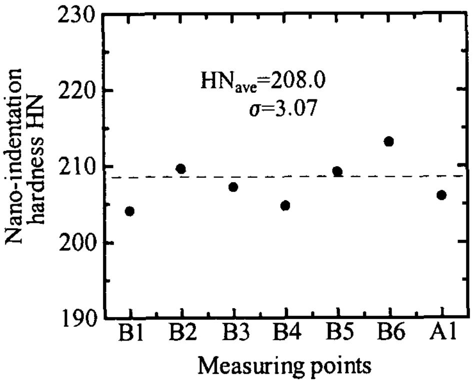

Fig.5 Hardness HN distribution in B direction

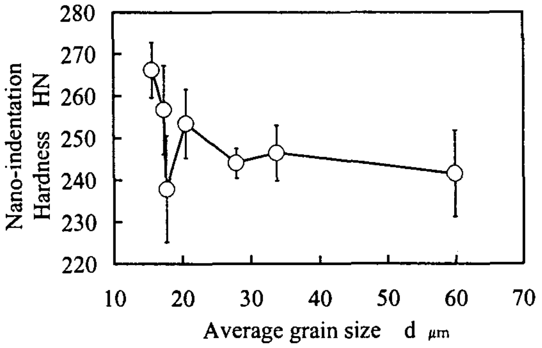

Fig.6 Recrystallized average grain size and nano indentation hardness for upsetting

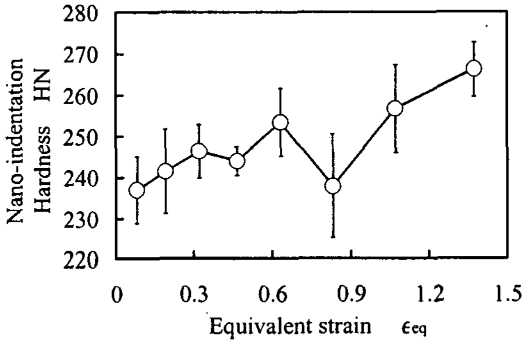

Fig.7 Equivalent strain and nano-indentation hardness for upsetting

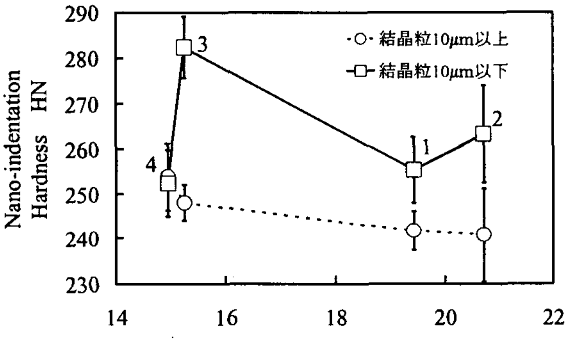

Fig.8 Recrystallized average grain size and nano-indentation hardness for ECAP

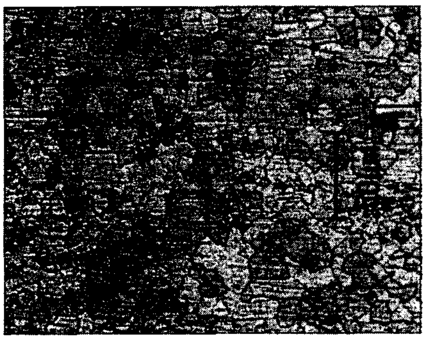

Fig.9 Microstructure of A7050 alloy

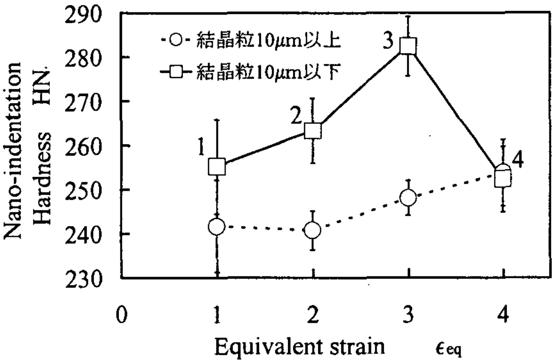

Fig.10 Equivalent strain and nano-indentation hardness after T6 by ECAP