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THE DEVELOPMENT OF SUS 316L BONE PLATE FORGING PROCESS BY COMPUTER SIMULATION TECHNOLOGY

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Abstract

Due to the strength and biocompatibility requirement, the stainless steel SUS 316L is widely used for trauma internal fixation device. SUS 316L can be hardened and strengthened only by cold work. In this work, the material compression test is performed both in laboratory and computer simulation by a FEM analysis software DEFORM to correlate the hardness to strain. This data is then used for preform design and predict the hardness of the finish bone plate forging. Finally, we compared the hardness between the actual forging and computer analysis results. Although the predicted hardness from computer simulation is 55HV higher than the final forging sample, we can get good compatibility on the hardening tendency of cold forging.

Keywords: bone plate, compression test, cold work hardening, forging simulation, hardness-strain relation

1. Introduction

The material used for orthopedic implant is that mimics the tissue with respect to its consistency, size and shape and yet yields no biological response [1]. The materials used today are stainless steels (e.g. SUS 316L), cobalt chromium molybdenum alloy and titanium alloy. Implants made by cobalt chromium molybdenum alloy and titanium alloy can be strengthened by heat treatment. SUS 316L has austenite matrix, which can only be strengthened by cold work. Although the correlation between cold work ratios to hardness data can be found easily [2], for high standard orthopedic implants it is insufficient for process design. Therefore a combine forging process of hot forging for mass deformation and cold forging for finish must be used to meet the geometry and properties requirement.

In this paper, the cold work hardening relative to strain and compression ratio is investigated by upsetting. This upsetting is also simulation using forging simulation software DEFORM to obtain the strain distribution. These two results are then correlated for hardness-strain relationship. This hardness-strain relation is used to get the proper preform design by converting the strain obtained from forging simulation to hardness. Through this process, a proper shape of preform can be obtained for both forging process design and hardness requirement. The predicted hardness distribution is compared to the victor hardness distribution of forgings.

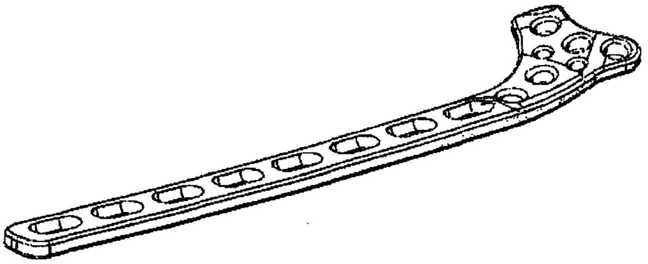

Figure 1. The model of bone plate studied in this paper

2. Compression test and simulation

2.1 Material Compression Test and Simulation

Material used in this study is SUS 316L stainless steel. All specimens are annealed at 1065˚C for 12 min and then quenched in water. These specimens are machined to cylindrical, 10 mm diameter, 15 mm high. The compression test is performed on MTS-810 with the speed of 0.2 mm/sec. The compression ratio and average hardness is shown in table 1. The hardness distribution in specimens is measured in 1 mm increment for both X and Y direction from center of section. Material compression is also simulated by DEFORM to obtain the strain distribution. Figure 2 shows the strain distribution and measured hardness at a compression ratio of 37.2%.

Table 1. Compression ratio and average hardness

NO	1	2	3	4	5
Original high (mm)	14.98	14.9	15.0	15.0	14.88
Deformation (mm)	2.78	4.1	5.58	6.95	8.16
Compression ratio(%)	18.6	27.5	37.2	46.3	54.8
Average hardness (Hv)	264.4	306.0	334.6	362.8	376.4

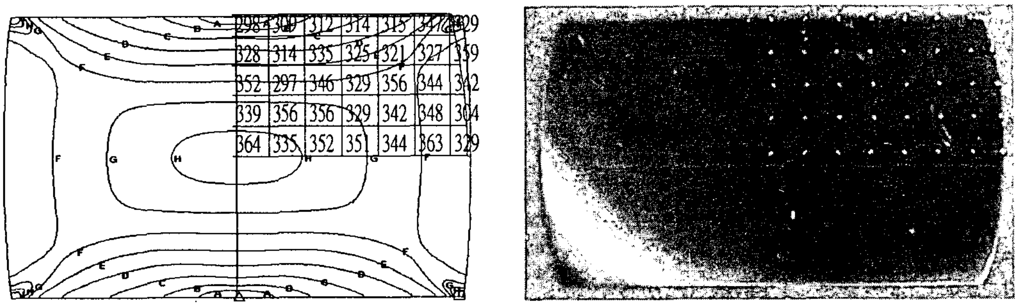

Figure 2. Strain distribution and experiment hardness at 37.2% compression ratio

2.2 Correlation of Hardness and Strain

The simulated strain correspond to hardness measurement location has been identified. The hardness acquired from experiment and the effective strain acquired from computer simulation is correlated by equation 1 with $R^2=0.9336$. (If R^2 is closer to 1, the reliability of equation is higher.) Figure 3 shows the fitted curve for experiment hardness to simulated effective strain. The experiment hardness are scattered within ±10% of fitted curve.

$$y = -237.29x^2 + 418.39x + 193.2 \tag{1}$$

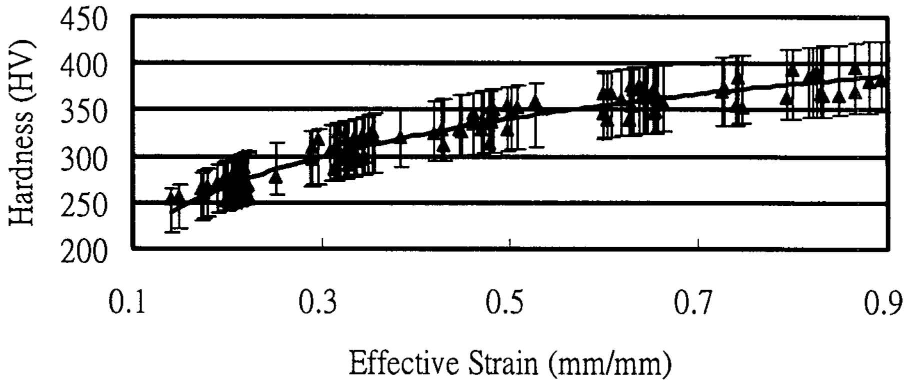

Figure 3. Fitted curve for hardness to effective strain

3. Forging simulation and practice

3.1 Blocker design and forging simulation

The blocker shape before cold forging has to satisfy not only product shape but also strength requirement. For product hardness of HRC 30-35 (HV 302-345), the effective strain should be between 0.3 and 0.55 and the corresponding cold work compression ratio is 27% to 42%. The blocker shape design is base on average compression ratio of 40%. Figure 4 shows the cross section shape of preform with thickness of 8.3mm for final product with 5 mm thickness. This cold forging process is also simulated for strain distribution. Figure 5 shows the effective strain distribution with a major range of 0.3 to 0.7.

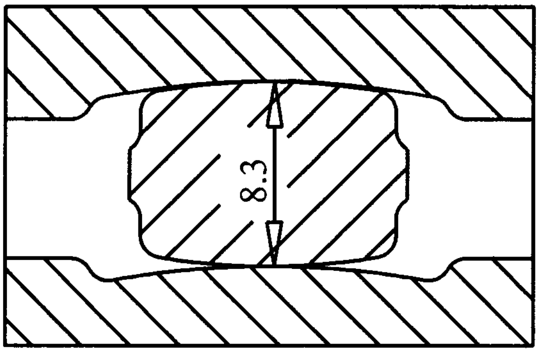

Figure 4. Blocker shape before forging

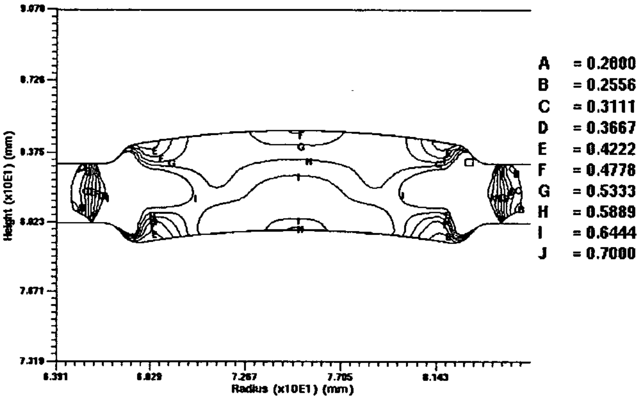

Figure 5. Strain distribution of forgings

3.2 Comparison of simulation result to measurements from forgings

The simulated strain has been extracted at specific location. Equation 1 is used to convert those strains to hardness. The predicted hardness is compared with measured value from forgings (figure 6). Figure 7 shows the predicted and measured hardness. The measured values are scatter within 10% of its fitted curve. The predicted hardening tendency of cold working has good compatibility with the actual forgings, although it has the difference of average HV55 on the hardness value.

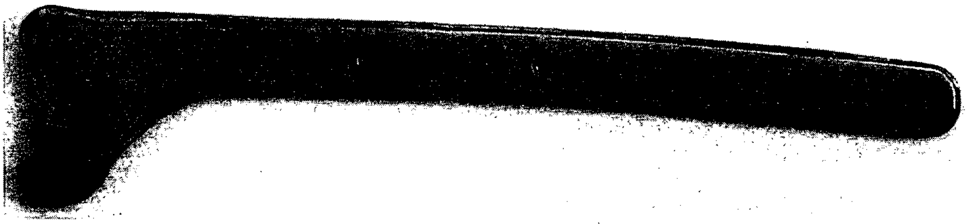

Figure 6. Cold forged SUS 316L Orthopedic Implant

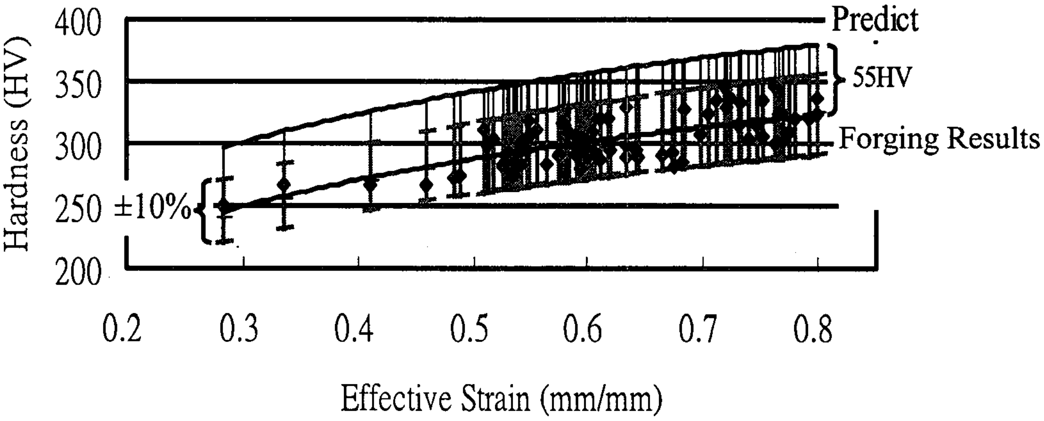

Figure 7. Hardness comparison of predicted and measured

4. Conclusion

1. Equation 1 is used for 316L cold work hardness prediction with strain range of 0.2 to 0.8.
2. The predicted hardness is higher than the value measured from forgings by 55 HV. This indicates that there is factors involve inducing the difference. The factors might include product shape, temperature rise during forging and friction condition. This need further investigate to identify the major factor and its influence.

5. References

[1] Paul Unwin; The Application of Titanium in Advanced Orthopedic; Proceeding; 2002International Symposium of Titanium and Bio-metal Applications in Taiwan, R.O.C. Nov. 21-22,2002, Taipei, Taiwan, R.O.C.

[2] Phil D. Harvey; Engineering Properties of Steel; American Society for Metals