

EFFECT OF ULTRASONIC VIBRATION ON THE METALLURGICAL PROPERTIES OF STEEL

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Abstract.- The influence of 20kHz ultrasonic energy on metallurgical properties of cold rolled sheet steel specimens during annealing was investigated. Acoustic energy caused an acceleration in grain growth rate. Annealing texture was also modified by ultrasound as well as the grain growth was enhanced. As a result of these effects, the ductility of the sheet steel for press forming was increased appreciably, and the drawability hence much improved. Efficiency of over-aging treatment in a continuous annealing process of sheet steel was nearly doubled by ultrasonic irradiation during over-aging.

1. **Introduction.**- A number of investigations have been reported on the effect of ultrasonic irradiation to metals. It is generally accepted that in certain circumstances ultrasonic irradiation during processing of metals can improve metallurgical and mechanical properties of them. But as for steels, the reports are rather scarce and the effects reported fairly diverged, though from practical points of view it has been highly desired to make clear the improving effects of ultrasonic irradiation on steels quantitatively. Therefore we have made a series of experiments in order to clarify the effect of ultrasonic vibration on the metallurgical and mechanical properties of low carbon aluminum-killed and rimmed steels and of 3%-Si steel, when it is irradiated to the specimens during recrystallization annealing and also during cooling after annealing.

2. **Experimental.**- Commercial low carbon steels for press forming and 3%-Si steel were used as specimens, and a vacuum-remelted electrolytic pure iron was also used for comparison. Specimens were obtained as cold rolled sheets, and were annealed with or without ultrasonic irradiation.

The acoustical system consisted of an ultrasonic power generator (nominal maximum output 1kW), a lead zirconate/titanate (PZT) ceramic transducer, booster horn, exponential horn and specimen. It is shown schematically in Fig.1. The specimen was cut to a tensile specimen

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(JIS 13B). One of grips was extended so as the total specimen length equalled the wave length. A standing ultrasonic wave with a frequency of about 20kHz was excited in a longitudinal mode, and the whole system was designed so that the maximum stress was exerted at the middle of the tensile specimen. In Fig.1 is also shown schematically how the longitudinal displacement amplitude varied along the specimen.

Annealing of specimen was done in a molten salt bath. The whole acoustical system could be moved vertically in a quick way. Ultrasonic irradiation was thus done for any desired length of duration at any desired stage of annealing, say only at heating-up or at holding time or both.

Tensile testing was made after heat treatment with an Instron-type tester. An ordinary stress-strain curve was obtained and the Lankford r -value was measured, too. A conical cup testing value, CCV, is often adopted as drawability index of sheet steels for press forming. For this purpose rectangular specimens with the width of 50mm, and of the half wave length, were annealed and ultrasonically irradiated.

Along with mechanical testings, recrystallization grain growth was investigated micrographically and the annealing texture was also determined by X-ray reflection method. Reflection intensities from (222), (112), (200) and (110) planes were determined with respect to a random orientation specimen.

3. Results and Discussion.

3.1. Grain Growth Enhancement.-

Effects on grain growth was studied by irradiating ultrasound to cold-rolled 3%-Si steel sheet specimens during annealing at a temperature between 800 to 1000°C for 1 min. A typical example of significant enhancing effect is seen in Photo.1. Fig.2 shows how the largest grain size varied with annealing temperature. It was concluded that the

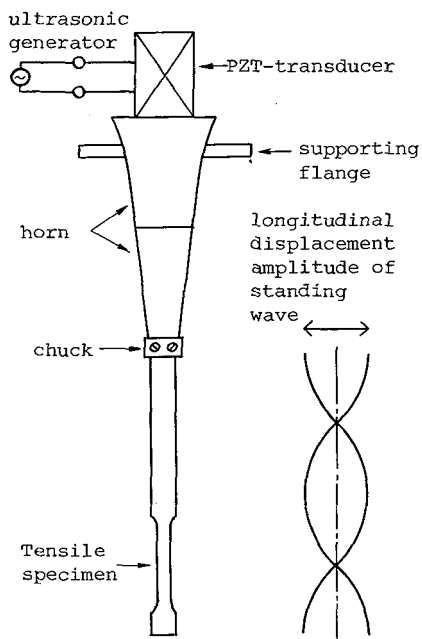


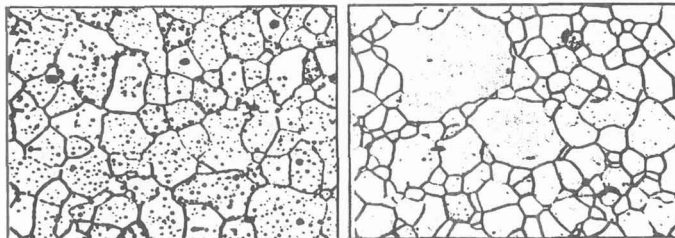
Fig.1 : Schematic diagram of acoustic system, showing how longitudinal displacement amplitude varies as a function of position.

grain growth enhancement effect due to ultrasound corresponded, roughly speaking, to increasing of the annealing temperature by about 100 degrees. The effect was most prominent where the stress was maximum, i.e., at the position of the node of the standing wave, and almost null at the loop.

3.2. Effects of Improvement in Workability.- Prior to annealing at 700 °C for 1 min. a preannealing between 400 to 640°C for 1 min. was given to cold rolled sheet specimen of low carbon rimmed steel. Ultrasound was irradiated only during preannealing. Two levels of stress intensities were adopted. In Fig.3 are shown Lankford r -values against the preannealing temperature. The drawability of the annealed specimen was improved significantly by ultrasonic irradiation, the effect being greater for stronger ultrasound except a single case in which cracks at grain boundaries, caused by the stronger ultrasonic irradiation at the highest preannealing temperature, lowered r -value on the contrary. Conical cup testing results on aluminum-killed steel specimens are shown in Fig.4. Ultrasonic irradiation resulted in much lower CCV, which means a very prominent improvement in drawability.

3.3 Effect on Annealing Texture.- Effect of ultrasound on annealing texture of pure iron, 3%-Si steel and mild steel, as determined by X-ray reflection, is shown in Fig.5. The effect of ultrasound was obviously influenced by the time of irradiation. If irradiation was done during heating-up the 111 component was increased, while during hold-time it was rather decreased.

3.4 Effect on Precipitation of Interstitial Atoms.- Interstitial atoms retained in solution are harmful for sheet steel because they appreciably lower the ductility of it. Therefore, an over-aging treatment is usually adopted in a continuous annealing process of low carbon sheet steels for press forming. The effect of ultrasonic vibration during over-aging was examined. Fig.6 shows the ductility of irradiated spe-



left: without ultrasonics.

right: with ultrasonic irradiation.

Photo.1 : Grain growth enhancement in 3%-Si steel due to ultrasonic irradiation during annealing. (900°C X 1 min)

cimen increased with over-aging time much faster than that of the unirradiated one. The efficiency of the over-aging was nearly doubled.

3.5. Discussion.— Fairbanks and Dewez (1) reported that the ultrasound with a frequency of 400 or 100kHz caused a conspicuous grain refinement in low carbon steel when the irradiation was done during α - γ phase transition on cooling. The grain refinement was presumably due to the acceleration of ferritic grain nucleation by ultrasonic vibration. In the present experiment, the grain growth acceleration took place instead of refinement. Hayes and Shyne (2) reported an ultrasonic enhancement of grain growth in pure copper, and argued that the acoustic

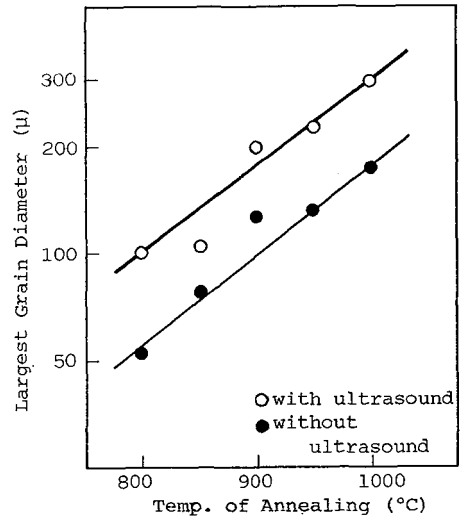


Fig. 2 : Grain Growth Acceleration by Ultrasonic irradiation.

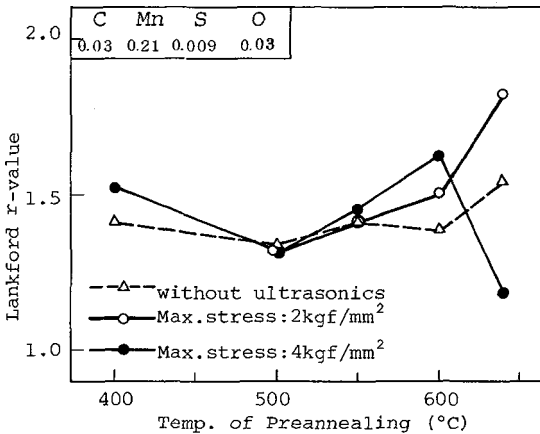


Fig. 3 : Effect of ultrasound on Lankford r-value of rimmed steel, irradiated during preannealing only.

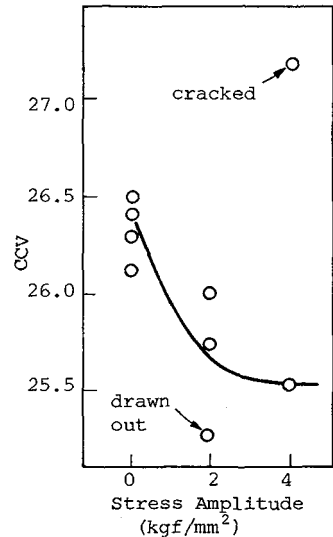


Fig. 4 : Effect of ultrasound on CCV of Al-killed steel, annealed at 850°C for 2 min.

stresses decreased grain boundary pinning, causing boundaries to be more mobile.

It is worth noting that the influences of ultrasound on annealing texture formation are definitely different depending on whether the irradiation was done during heating-up or at holding time. During heating-up the annealing was at such a stage that recrystallization nuclei were being formed from the strained matrix, while at the holding time the grain growth was taking place. Our experimental results suggest that the interactions between ultrasonic vibration and grain boundaries are different for these two stages.

From a practical point of view, a fact that the ultrasonic irradiation accelerates the precipitation of interstitial atoms is very important. Hayes and Shyne (3) reported that the precipitation in Cu-Be alloy was accelerated by the ultrasonic irradiation about 1.5 times. Present result that the efficiency of over-aging was nearly doubled by ultrasonic irradiation seems to be consistent with their result. Walker et al. (4) insisted, from experiments on zinc and nickel, that there is no enhancement effect of diffusion by ultrasonics. If it is the case for carbon or nitrogen atoms in steel, an enhancement of the formation of precipitation nuclei due to ultrasonic vibration might be taken into account.

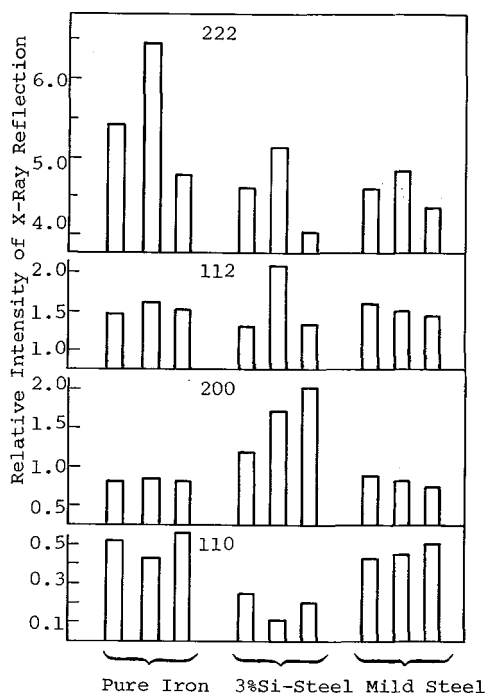


Fig.5 : Effect of ultrasound on the formation of annealing texture.

Left: without ultrasonics.
Middle: irradiated during heating-up.
Right: irradiated at holding time.

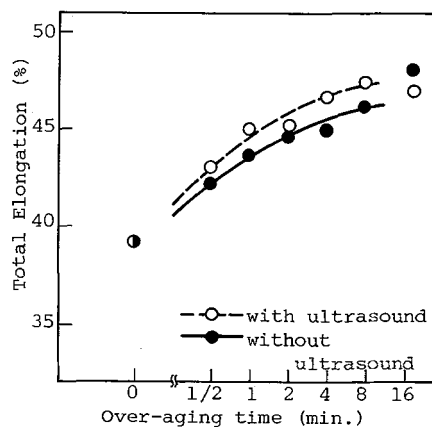


Fig.6 : Effect of ultrasound on the ductility of rimmed steel; irradiated during over-aging at 300°C, after annealing at 700°C for 1 min.

4. Summary.- Ultrasonic irradiation to cold rolled sheet steel during annealing resulted in a significant grain growth enhancement, while the the annealing texture was also modified. In consequence, the mechanical properties such as ductility or drawability were improved greatly. An acceleration in the precipitation of interstitial atoms was also achieved by ultrasonic irradiation, which nearly doubled the efficiency of over-aging treatment in a continuous annealing process.

References.

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