JOURNAL OF MATERIALS SCIENCE 24 (1989) 2147–2150

Enhanced activity of austenite resulting from ultrasonic vibration in a low alloy case-hardened steel

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The retained austenite content of a quenched case of a low alloy steel was examined with and without ultrasonic vibrations. Results obtained are particularly promising and indicate the possibility of reducing the amount of retained austenite in a quenched case-carburized steel by ultrasonic treatment which is of considerable industrial importance. The activity of the austenite to form more martensite has been attributed to the increase in dislocation density and point defects which enhance the number of martensite nucleation sites on ultrasonic treatment.

1. Introduction

Ultrasonic waves have tremendous application potential, but their potential to physical metallurgical applications, especially those pertaining to the area of heat treatment, has been exploited only to a very limited extent. A number of papers pertaining to the use of ultrasonic vibrations as an aid to the heat-treatment processes have appeared only within the last decade, mostly from the Soviet Union. Vasudevan and his group [1, 2] have summarized the use of ultrasonic vibrations in industrial heatment. From their experimental results, they have clearly established the advantage of using ultrasonic waves as a tool in different heat treatments. The complete elimination or minimizing of retained austenite content of a quenched tool steel or case-carburized steel is important in industrial heat treatment. Austenite is a soft phase compared to martensite and the wear rate of hardened steel is very much increased if retained austenite is not eliminated. Moreover, retained austenite acts as a soft spot in quenched tool steel and may be the cause for crack initiation under severe working conditions of the tool. In view of this, any method which will reduce the retained austenite content is a boon in tool steel heat treatment.

The effect of ultrasonic vibrations on the austenite to martensite transformation in steels has received very little attention. The data available on this subject are also meagre. It was Ramachandran and Dasarathy [3] who first observed higher hardening in a few steels when quenching was carried out in baths agitated ultrasonically. From their experiments, they have shown the activation of ultrasonically bombarded austenite and more martensite was observed under these conditions after quenching the steel. They attributed the activation of the austenite to the localized lattice disturbances resulting from the passage of certain types of acoustic energy in the austenite.

By conducting experiments similar to the Jominy end-quench test, Vasudevan [2] has shown that there is an increase in the depth of hardening of some steels on ultrasonic agitation of the quenching medium. According to Vasudevan [2], ultrasonic vibrations may cause drastic reduction of an unwanted vapour blanket stage of the quenching process and quenching in an ultrasonically agitated bath can give better results than a simple mechanical agitation of the quenching media can bring about.

This investigation was undertaken to study the effect of ultrasonic waves on the retained austenite content of a quenched case-carburized low-alloy steel. Analysis of the experimental results is presented with reference to the activity of the austenite. The increase in the proportion of martensite and the corresponding increase in hardness, when austenite transforms on quenching to a fixed reference temperature, would serve as a convenient parameter for indicating the extent of activation of austenite. Such activation has been experimentally detected and is described below.

2. Experimental procedure and results

2.1. Material used in the investigation

The chemical composition of the steel (wt %) used in the investigation is as follows; C 0.18, Si 0.20, Mn 0.60, S 0.05, P 0.05, Ni 3.75 and Fe balance. The steel is of a case-hardening variety, which was available as hot-rolled rods. After annealing in pure argon atmosphere, the round rods were machined to 20 mm diameter from which 8 mm thick discs were cut for subsequent investigations.

2.2. Carburizing

A high-temperature cyanide bath consisting of sodium cyanide, barium chloride, potassium chloride, sodium chloride and sodium carbonate, was used for carburizing. The specimens were carburized at 930° C. The above bath is usually preferred for rapid development of a case depth of 1 to 2 mm. The specimens were

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TABLE I Results of the heat treatments of the specimens investigated

Sample no.	Heat treatment	VHN of the case* (10 kg load)	Retained austenite content of the case (vol %) (X-rays)
1.	Steel austenitised at 790° C, soaked for half an hour and quenched in water at 27° C.	810	15.1 ± 0.5
2.	Steel austenitised at 790° C, soaked for 0.5 h and quenched in boiling water which is ultrasonically vibrated and finally quenched in water at 27° C	855	9.8 ± 0.5

*Mean of five perfect impressions.

carburized for 5 h to achieve a case depth of 1 mm. The samples were cooled in air and salts removed by thoroughly washing in water. The carbon content of the case was evaluated and was found to be 1% carbon. A normalizing treatment of the specimen was carried out to eliminate coarsened grain structure of the core during high-temperature carburizing, by heating the carburized samples above 850° C and holding at this temperature for 30 min and subsequently cooling in air.

2.3. Effect of ultrasonic vibrations on the retained austenite content of the quenched case

To ascertain the effect of ultrasonic waves on the retained austenite content of the case, heat treatments were carried out with and without ultrasonic vibrations. The specimen soaked at 780° C for 0.5 h in a very pure argon atmosphere was quenched in water at 27° C which was used as final reference temperature. Another specimen soaked in a pure argon atmosphere for 0.5 h was quenched in boiling water at 100° C which was intensely ultrasonically vibrated using an ultrasonic vibrator IMECO type (maximum capacity 1000 W, tank dimensions 15 in. × 10 in. × 12 in., frequency 23 kHz with a lead zirconate titanate crystal) for 5 min and quenched in water at 27° C.

The retained austenite contents of the cases of the specimens treated in the above manner were determined by X-ray method and verified by metallographic method after each heat treatment. The retained austenite contents of the cases and the corresponding Vickers hardness numbers of the two heat treatments shown in Table I are the mean of five experiments using samples 1 and 2. A detailed account of the method of estimation of retained austenite, the problems associated with the determination and accuracies of the methods of measurement are discussed in an earlier paper [4]. Figs 1a and b are the respective microstructures of cases of specimens quenched in water without and with ultrasonic treatment. Figs 2a and b are the X-ray diffractograms of 200 reflections of austenite and martensite of the cases of specimens quenched in water without and with ultrasonic vibration. These results clearly demonstrate that the case of the case-carburized steel subjected to intense ultrasonic bombardment before quenching to the final temperature transforms to martensite to a greater extent, thereby indicating that ultrasonic bombardment has increased the activity of austenite to form martensite.

3. Discussion

Ramachandran and Dasarathy [3] introduced the concept of activation of austenite to form martensite in terms of the additional "strain embryos" or "martensite nucleation sites" generated in the austenite. According to their view, the increase in proportion of martensite and the corresponding increase in hardness, when austenite transforms on quenching to a fixed reference temperature would serve as a convenient parameter for indicating the extent of activation. According to the above investigators, intense ultrasonic waves produce innumerable shock waves and these propagate from the entire surface of the specimen into the interior due to an extremely large number of cavities collapsing at the specimen surface. According to Ramachandran and Dasarathy, due to successive reflections at the bounding surfaces of each of these shock waves, the resultant stress distribution would be extremely complex and can be considered to throw the structure into considerable disorder, resulting in the generation of many strained regions or embyros. This would lead to an increased activity when austenite is ultrasonically bombarded before being cooled to a fixed reference temperature. The above workers confirmed their concept by subjecting several steels to ultrasonic bombardment. Later Vasudevan [2] showed that there is a greater depth of hardening of some steels if the bath in which they are quenched is subjected to ultrasonic vibration.

In the present investigation intense ultrasonic vibrations were made to pass through the case-carburized sample before it was quenched to the final temperature. The results shown in Table I, Figs 1a and b, 2a and b vividly demonstrate that powerful ultrasonic vibrations have a significant effect on the amount of retained austenite content in the quenched case. The activity of austenite has increased due to ultrasonic bombardment.

Langenecker and Fauntain [5] observed that ultrasonic vibrations having an intensity of the order of $15\ \mathrm{W\,cm^{-2}}$ at 20 kHz caused pronounced hardening in some alloys. Bazelyuk *et al.* [6] found that by subjecting some polycrystalline metallic samples to ultrasonic vibrations there was an increase in dislocation density and coalescence of point defects. They found that on further irradiation, the dislocations were found to interact with the Frank network. Gindin *et al.* [7] have shown that ultrasonic treatment of a material can cause massive generation of line and point defects. The dislocation density at low temperature, according to the above investigators increases the inhomogeneity of dislocation structure. Shea and Rao [8] found higher dislocation density and resulting hardness of the surface region in an ultrasonically vibrated specimen. It

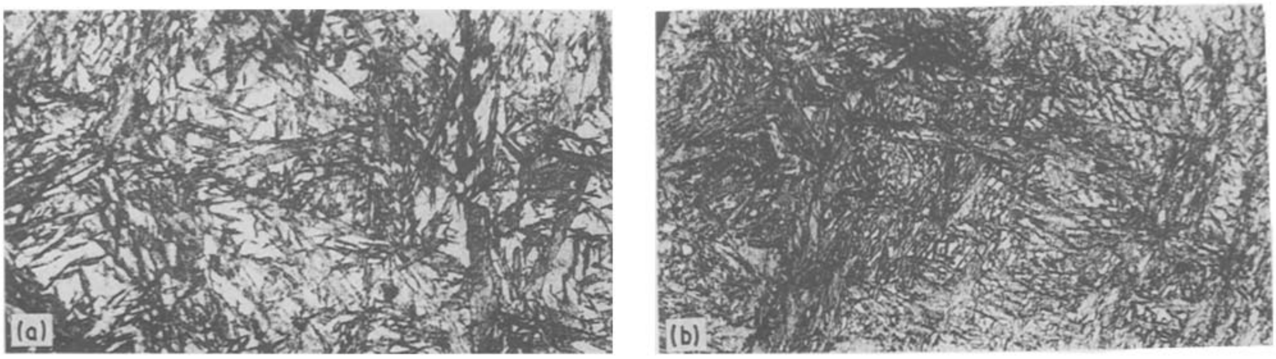

Figure 1 Microstructure of the case – austenised steel (a) quenched in water at 27° C, (b) ultrasonically bombarded and quenched in water at 27° C. ×800.

appears, therefore, that the activity of the austenite to form martensite in the present work results from intense ultrasonic waves travelling through the sample which increase lattice imperfections. Under these conditions it is likely that a number of martensite nucleation sites are generated in the austenite. This is evident from the work of Bezelyuk *et al.* [6]. Vasudevan and his group [2], using transmission electron microscopy (TEM) have shown the presence of strain fields and a dislocation substructure in an ultrasonically treated sample. They also mention the production of a large number of dislocations and point defects by ultrasonic treatment of metallic samples. It should be pointed out that weak ultrasonic waves which are generated in ultrasonic cleaners are found to have no significant effect in generating lattice imperfections. In our opinion, powerful ultrasonic vibration of austenite produces a number of martensite nucleation sites which is responsible for the increased activity of the austenite. Incidentally, it may be mentioned that when austenite is deformed below the M_d temperature, the activity of austenite is increased which is attributed to the generation of a number of martensite nucleation sites.

According Vasudevan and co-workers [2, 3] ultrasonic treatment produces an equivalence of cold work. Shea and Rao [8] explain the higher dislocation density and resulting hardness in ultrasonically vibrated specimens on the basis of higher dislocation activity due to intense ultrasonic vibration. Thus the increased activity of the austenite to form martensite by ultrasonic bombardment may be attributed to the increase in the number of martensite nucleation sites. This result is consistent with the results of Ramachandran

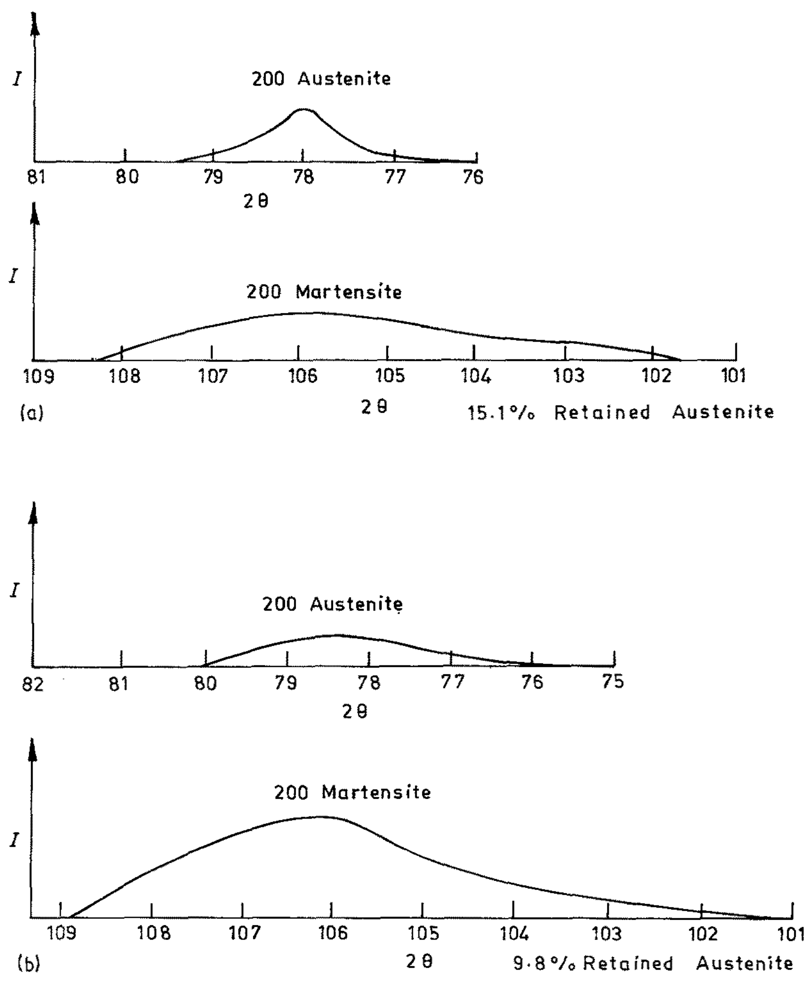

Figure 2 X-ray diffractogram traces of 200 reflections of austenite and martensite of the case – austenitized steel quenched (a) in water at 27° C, and (b) in water at 27° C after ultrasonic bombardment.

and Dasarathy, Vasudevan and with our earlier work [9].

Further work to clearly establish the nature and number of martensite nucleation sites in an ultrasonically treated sample is necessary. The result presented here is of a preliminary nature. Ramachandran and Dasarathy [3] have shown the reactivity of the stabilized austenite. Research work to minimize or completely eliminate the retained austenite in a quenched case-carburized steel using ultrasonics is necessary. Investigation along these lines is in progress and will be reported shortly.

4. Conclusion
Intense ultrasonic bombardment of a case-carburized low-alloy steel before it is quenched to the fixed temperature has significantly reduced the amount of retained austenite. The results in Table I and Figs 1 and 2 show an increase in the activity of austenite caused by ultrasonic bombardment. The increase in the activity is attributed to the increase in line and point defects which enhance the number of martensite nucleation sites. This result has considerable significance in industrial heat treatment to reduce the amount of retained austenite in quenched case-carburized steel.

Acknowledgements
The author thanks Professor R. Vasudevan for providing ultrasonic facilities to carry out the investigation, Professor V. M. Radhakrishnan for his kind interest in this investigation, and also Professor L. S. Srinath, Director, IIT, Madras, for permission to publish this work.

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Received 15 March and accepted 5 September 1988