PRECIPITATION AND FERRITE RECRYSTALLIZATION IN HIGH STRENGTH LOW ALLOY STEELS

PRABIR DEB

Applied Mechanics Department

Submitted

in fulfilment of the requirements

of the

Degree of Doctor of Philosophy

to the

Indian Institute of Technology,

Delhi

February 1980

IN MEMORY

OF

MY FATHER

CERTIFICATE

This is to certify that the thesis entitled "Precipitation and ferrite recrystallization in high strength low allow steels". being submitted by Prabir Deb to the Indian Institute of Technology, Delhi, India, for the award of the degree of Doctor of Philosophy in Applied Mechanics is a record of bonafide research work carried out by him under my supervision and guidance. The thesis work, in my opinion has reached the standard fullfilling the requirements for the Doctor of Philosophy Degree. The research report and results presented in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

V. Raghavan 13/2/80

(V. Raghavan)
Professor
Department of Applied Mechanics
Indian Institute of Technology
Hauz Khas, New Delhi-110029,
India.

ACKNOWLEDGEMENTS

The author takes the opportunity to express his deep sense of gratitude to Professor V. Raghavan who introduced the author to the present problem "precipitation and ferrite recrystallization in high strength low alloy (HSLA) steels". The author is also very thankful to him for his valuable suggestions, able guidance, encouragement and englightening discussions in all stages of this work.

The author extends his thanks to Dr. V. Ramaswamy for his valuable suggestions and constant help. He also acknowledges the assistance from the Steel Authority of India Limited in providing the steels.

The author wish to extend his thanks to Professor T.R. Ramachandran, Professor A.K. Jena, Dr. R.K. Pandey and Dr. S.K. Gupta for helping at various stages of this work.

The author is grateful to Mr. Samar Das for his technical assistance during transmission electron microscopic studies.

The author acknowledges with gratitude the assistance he has received from his co-workers in preparing the manuscript, especially Mr. A.N. Kumar, Mr. B. Bhattacharya, Mr. R. Datta, Mr. B. Maiti and Mr. Prem Singh.

The author is thankful to Mrs. S. Malik for typing the thesis.

Prabir Deb

ABSTRACT

High strength low alloy (HSLA) steels developed in recent years satisfy the need for inexpensive, strong, tough and easily weldable steels for various structural applications.

To bring about these properties, microalloying elements are added to HSLA steels. The common additions are niobium (Columbium), vanadium, titanium and the rare earths.

Besides microalloying additions, the grain refinement of austenite or ferrite can also be achieved to a great extent by "controlled-rolling". Both precipitation and recrystallization processes are known to take place simultaneously during the controlled rolling of HSLA steels in the austenitic region. These phenomena have been studied extensively. However, the tail-end of the controlled rolling which may well be into the ferritic region, has not received sufficient attention. Therefore, the subject of the present investigation is the precipitation and recrystallization behaviour of HSLA steels in the ferritic region.

The following experimental techniques have been used to study the simultaneous precipitation and recrystallization phenomena:

(i) resistance measurements,

(ii) transmission electron microscopy (TEM),

(iii) quantitative metallography and

(iv) hardness measurements.

Four different thermomechanical treatments were given to all steels. In treatment I, all steels were given 50% reduction by rolling at 700°C and subsequently annealed at 700, 650, 600 and 550°C for various annealing times ranging from 5 to 300 minutes. In treatment II, temperature of annealing (T_a = 650°C) and degree of deformation (ϵ = 50%) are kept constant and the temperature of deformation is varied, viz. 700, 650, 600, 550 and 25°C. In treatment III, the temperature of deformation (T_d = 700°C) and the temperature of annealing are kept constant and the degree of deformation is varied, namely, ϵ = 50, 37.5 and 25%. In treatment IV, the four steels were given 50% reduction at various temperatures of deformation without any subsequent anneal.

A wide range of variation in $\Delta R/R$ values from $\sim$ - 0.07 to $\sim$ 0.43 is observed in the different steels. The C-Mn steel shows the maximum positive variation in $\Delta R/R$ values. In the absence of information about specific atomic processes which are responsible for the resistance changes, no detailed interpretation of the $\Delta R/R$ data is given.

Three distinct size groups of precipitates have been observed during TEM studies. The first group is spherodized cementite particles in the size range of 5000 to 10000 Å. The second group consists of cementite precipitated in ferrite in the size range of 1000 - 2000 Å and the third group is micro-alloyed carbides in the size range of 200 to 800 Å. All these particles are in size range larger than the critical size required for pinning down migrating grain boundaries during recrystallization.

The recrystallization kinetics shows interesting variations in different steels for different thermomechanical treatments. In general, the extent of recrystallization is a maximum in C-Mn steel, followed by C-Mn-V steel. The C-Mn-Nb-V steel shows an intermediate behaviour. The C-Mn-Nb steel exhibits slowest recrystallization rate. As a function of temperatures of annealing, C - curve, anti C- curve, Z - curve and S - curve behaviour has been observed. This indicates that precipitation is having a complex effect on the recrystallization process.

In treatment IV, the hardness increase during deformation is mainly due to dynamic strain ageing and this effect is more in the C-Mn steel as compared to the microalloyed steels.

CONTENTS