THE INFLUENCE OF STRESS AND STRAIN ON THE TEMPERING OF SAE 4340 *MARTENSITIC* STEEL

Rochim Suratman*)

ABSTRACT

An investigation into the influence of stress and/or strain on the tempering of SAE 4340 martensitic steel is being done.

The as-quenched steel is tempered at several temperatures (100° - 600°C) with and without the influence of stress. The resulting changes in hardness and structure were then followed by microhardness measurements and electron microscopy. The primary variables of interest in this work are hardening conditions, tempering time, tempering temperature, stress, and strain during tempering.

From the experimental result it appears that the hardness of steel SAE 4340 tempered under stress between 100°C and 300°C is higher than the hardness of the same steel tempered without stress, while the hardness of steel tempered under stress at a temperature higer than 300°C is lower than the hardness of steel tempered without stress.

In all cases, at higher stresses the specimens undergo plastic deformation during tempering and it is seen that the plastic strain has more influence on the tempering than the stress.

The electron microscopic observations show that the increase in hardness, due to the strain occuring during tempering, is caused mainly by a more abundant precipitation of carbides of about the same shape and size as in specimens tempered without stress. When the strain occuring during tempering causes a lower hardness, the carbide precipitations are coarser, more equiaxed and fewer than after tempering without stress.

SARI

PENGARUH TEGANGAN DAN /ATAU REGANGAN YANG DIBERIKAN PADA SAAT MENEMPER BAJA MARTENSIT SAE 4340

Suatu penyelidikan mengenai pengaruh tegangan dan/atau regangan yang diberikan selama menemper baja martensit SAE 4340 terhadap proses penguraian martensit dan proses presipitasi.

---

*) Lab. Metalurgi Fisik, Jurusan Mesin – ITB.

Hasil-hasil percobaan menunjukan bahwa kekerasan baja SAE 4340, setelah ditemper pada suhu antara 100°C dan 300°C di bawah pengaruh tegangan, lebih keras dibandingkan dengan kekerasannya setelah ditemper tanpa pengaruh tegangan.
Setelah ditemper di bawah pengaruh tegangan pada suhu yang lebih tinggi dari 300°C, kekerasan dari semua baja yang diamati menjadi lebih rendah dibandingkan dengan kekerasannya setelah ditemper tanpa pengaruh tegangan.

Dari hasil pengamatan dengan bantuan mikroskop elektron, ternyata bahwa penyebab dari bertambah kerasnya kekerasan baja setelah ditemper di bawah pengaruh tegangan, adalah adanya presipitat-presipitat yang jauh lebih banyak jumlahnya dibandingkan dengan jumlah presipitat-presipitat yang ada setelah ditemper tanpa pengaruh tegangan; sedangkan penyebab dari berkurangnya kekerasan baja setelah ditemper di bawah pengaruh tegangan adalah adanya presipitat-presipitat yang kasar dan lebih sedikit jumlahnya dibandingkan dengan presipitat-presipitat setelah ditemper tanpa pengaruh tegangan.

INTRODUCTION

The tempering under stress (TUS) has been the subject of numerous investigation [1 - 6]. The particular interest has mainly devoted to obtaining the best combination of strength and ductility. These treatments involve the introduction of stress and plastic deformation during tempering of steel. A number of investigators have shown that TUS at low temperature can result in significant improvement in strength[6] while stressing during tempering at high temperature has been found to accelerate softening [1 - 5]. However, the influence of this process on the mechanical properties, microstructural changes or strengthening/softening mechanisme at temperatures ranging from 100° to 600°C not been done.
The present investigation is concerned with establishing the effects of TUS on the hardness of steel. The microstructural changes accompanying the TUS are followed in order to provide an understanding of the hardness developed.

Experimental procedure

a. Material

The SAE 4340 steel was selected as representative of the low alloy martensitic high strength steel. It had a chemical composition (in wt %) of 0.4C, 0.76Mn, 0.31Si, 0.011S, 0.007P, 1.5Ni, 0.7Cr and 0.4Mo. This stell was received in the normalized condition and in the form of ϕ 20 mm bar stock.

b. Test specimen

A typical specimen for this work is shown in fig. 1. It is the same as the one used by Howes [(2)]. It has a cross section which varies by a factor of ten. Thus, under a constant load, the stress also varies by a factor of ten. The hardness produced after quenching along the specimen is shown in fig. 2a.

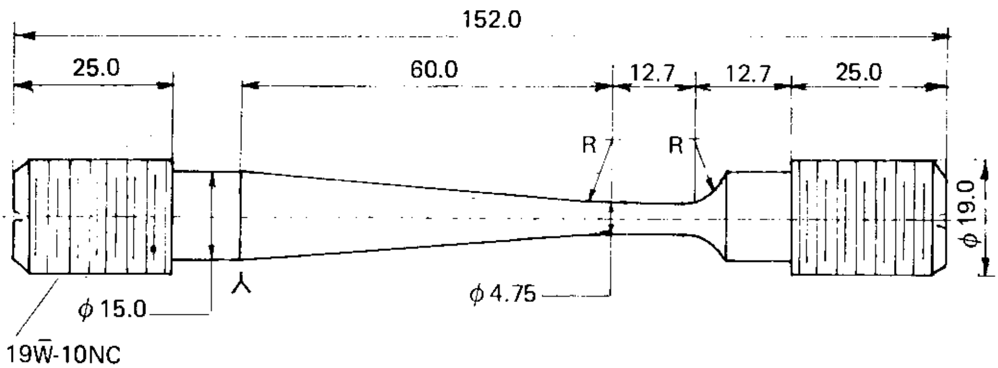


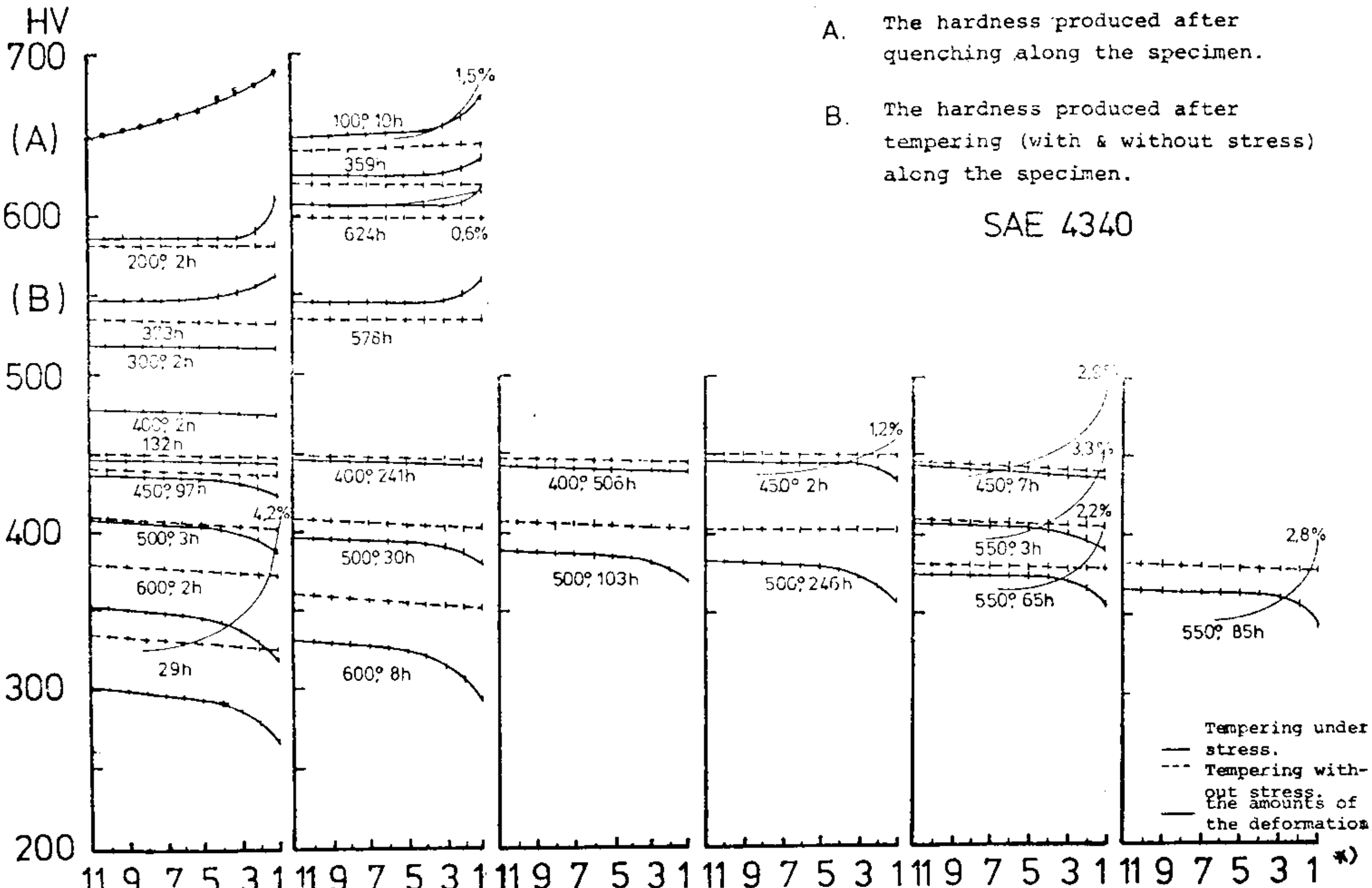
Fig. 1 Variable section creep specimens

c. Heat treatment

The heat treatment employed for this material is as folows: Austenizing at 850°C for one hour to ensure complete solution of carbides and quenching in oil. All the austenizing treatments were performed in a vertical Heraeus furnace in an atmosphere. The structure after quenching in oil contained twinned martensite plates (in the smallest cross section) and less twinned martensite plates (in the largest cross section of the specimen) and revealed no significant decarburization.

d. Test conditions

The tempering has been done at the temperatures of 100, 200, 300, 400, 450, 500, 550 and 600°C with and without the influence of stress. The TUS is executed in a stress rupture testing machine at constant load. The temperature of the furnace of the creep testing unit was regulated within ± 1°C of the set value. The tempering was usually pursued until the specimen failed in creep. The temperature along the specimen was monitor-



*) The odd number along the abcissa indicate the location of the hardness measurements as mentioned in fig. 2b.

Fig. 2a The hardness distribution along the variable section of the specimen

ed and controlled by three chromel alumel thermocouples attached along the specimen's gage section and the temperature varied less than ± 3°C along the gage length.
Tempering without stress was also carried out in the furnace of the creep testing unit.
After tempering the specimens were cross sectioned on a spark cutting machine (EDM – Servoment) into 11 pieces, and the variation of hardness with tempering time was followed using a Vickers pyramid hardness tester with a 30 kg load. The hardness value given for each specimen is the mean of four separate indentation measurements.
The hardness scatter is max. ± 5 HV of the average hardness line.
The same specimens were also used for optical and electron metallography.
The specimens for electron microscopy were first mechanically polished and final polishing was carried out at 15°C in a solution of 10 parts $HClO_4$ and 90 parts acetic acid using the "jet" method at 90 V.
The foils were examined in a Jeol CX 200 at 200 kV.

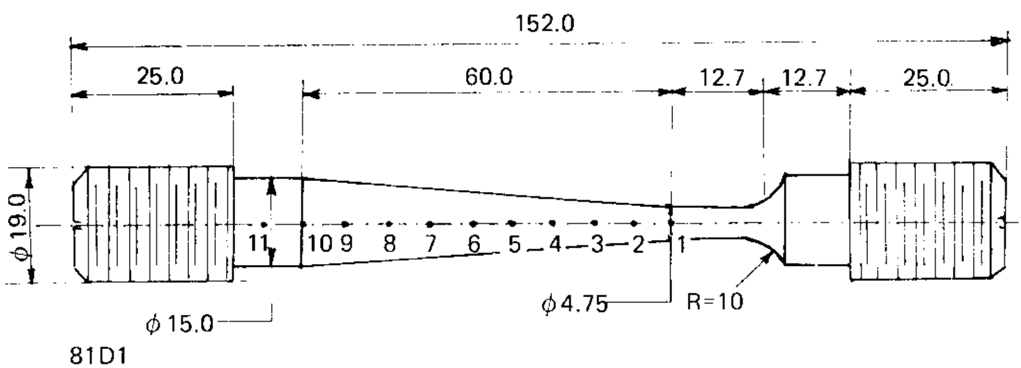


Fig. 2b Showing the locations of the hardness measurement along the variable section of the specimen. These locations are separated respectively about 7 mm

Results

Hardness

The variation of the hardness after TUS at 100, 200, 300, 400, 450, 500, 550, and 600°C for a given time over the range of stress levels is shown in fig. 3. The hardness distribution along the gage length of the specimen after tempering with and without stress for several exposure time is shown in fig. 2a. It will be seen from fig. 3 that the range of stress decreases as the exposure time increases since the specimens rupture in a shorter time as the load is increased. It

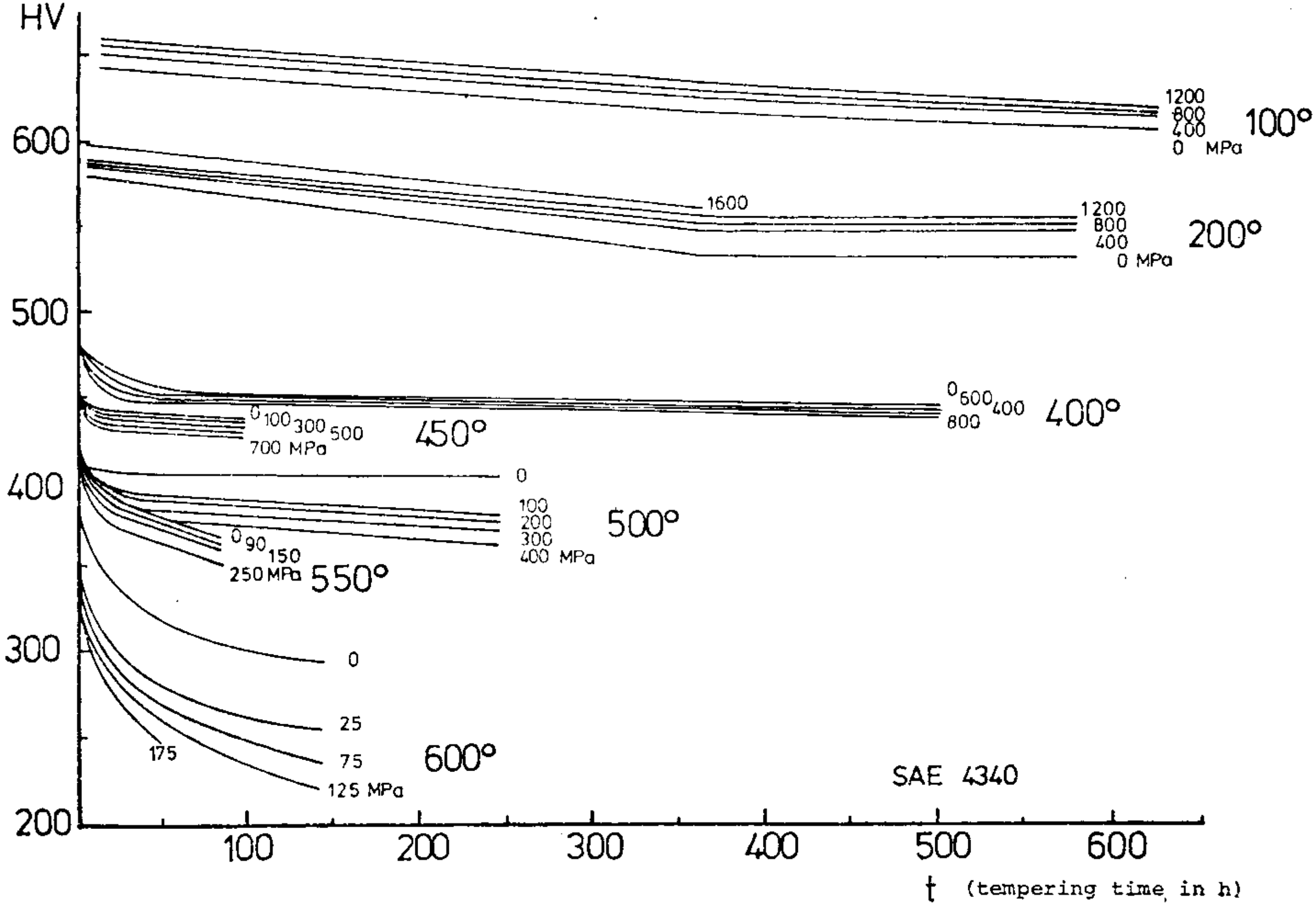


Fig. 3 Relation between hardness, tempering temperature and tempering time

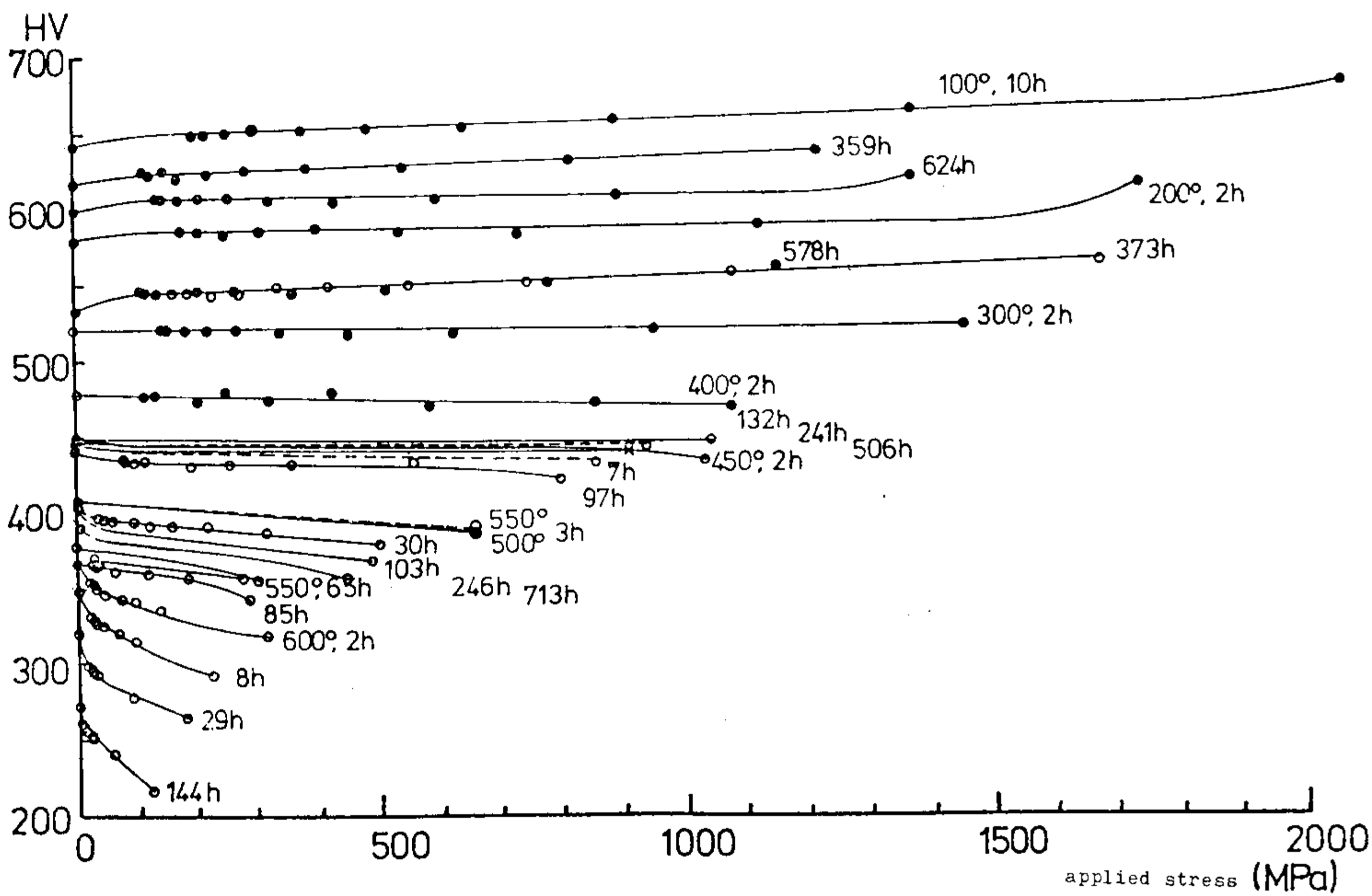


Fig. 4 Variation of hardness with cross section at 100°, 200°, 400°, 450°, 500°, 550° and 600 °C

also appears from fig. 2a that the hardness difference between "plain tempered" and "stress tempered" specimens increases with time, stress and temperature. The data shown in fig. 2a and 3 are replotted in fig. 4 to illustrate the variation of hardness after tempering with and without stress over a range of times and temperatures.

Microstructure

Fig. 5 and 6 are a transmission electron micrograph of : (a) The stress tempered specimen (1500 MPa) and (b) the plain tempered specimen after tempering for 373h at 200°C. Both structure exhibited the precipitate particles of about the same shape and size. The precipitate particles became coarser on tempering at 600°C and it was more pronounced at stress tempered specimen, as indicated in fig. 7.

Discussion

The fig. 2a indicates how the hardness deviates from the plain tempering curves when stress is applied during the tempering.
The deviation in hardness can be of two kinds:

a. A higher hardness after stress tempering at temperatures lower than 300°C.
b. A lower hardness after tempering under stress at temperatures higher than 300°C.

This deviation is mainly caused by the behaviours of the precipitation and transformation.
The stressing during tempering increases the value of the stored energy inside the metal. Such increment in the stored energy gives a contribution to the driving force for the precipitation and transformation.
The electron microscopic observations show convincingly that the increase in hardness, due to the stress applied during tempering, is caused mainly by a more abundant precipitation of carbides of about the same shape and size as is specimen tempered without stress. When the stress applied during tempering causes a lower hardness, the carbide precipitation are coarser, more equiaxed and fewer than after tempering without stress.

Conclusion

The effects of stress have been investigated on tempering of SAE 4340 martensitic steel. The tempering process is either retarded after tempering at temperatures lower than 300°C or accelerated after tempering at temperatures higher than 300°C.
The effect increases with increasing stress over the range studied.

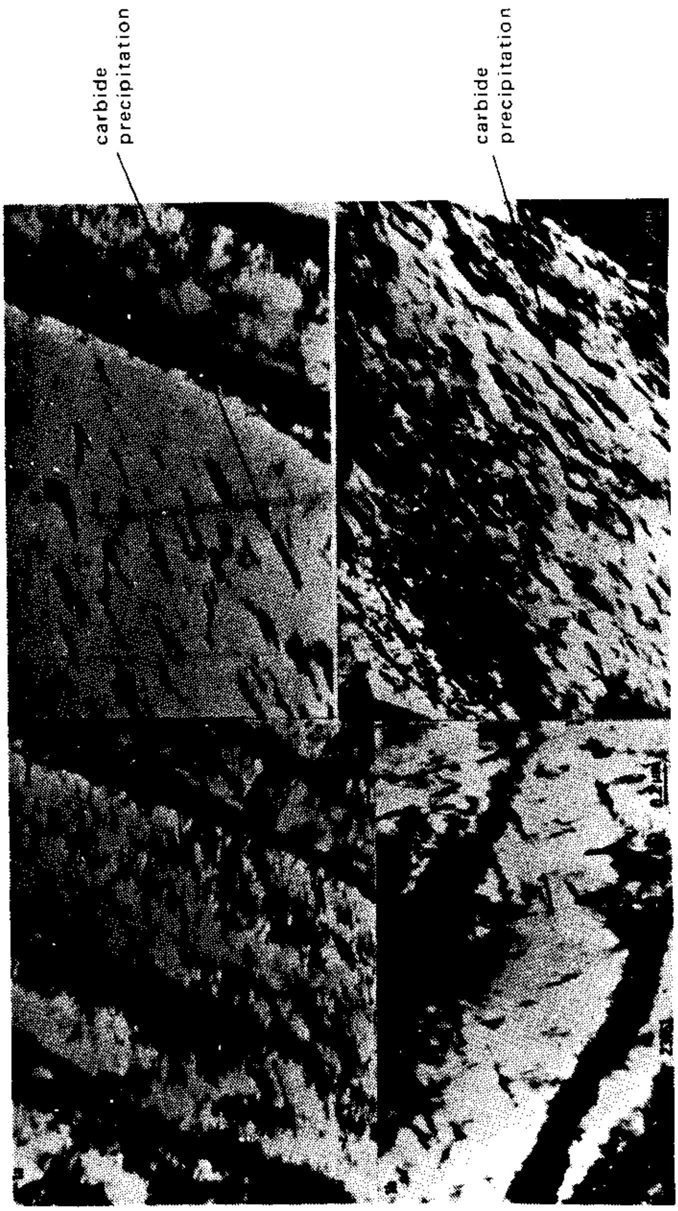


Fig. 5a

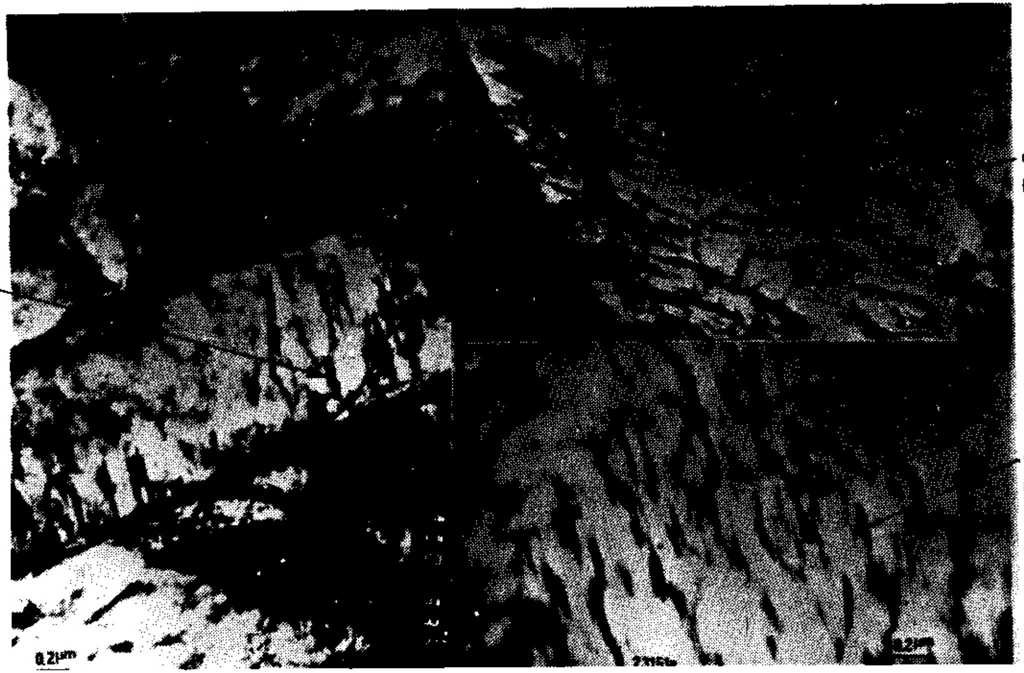


Fig. 5b

Fig. 5 The transmission electron micrograph of:

(a) The stress tempered specimen (1500 MPa) (page 9)

(b) The plain tempered specimen, after tempering for 373 h at 200°C.

Showing the abundance of carbide precipitation after tempering under stress.


carbide particle
carbide particle
carbide particle
carbide particle

Fig. 6a

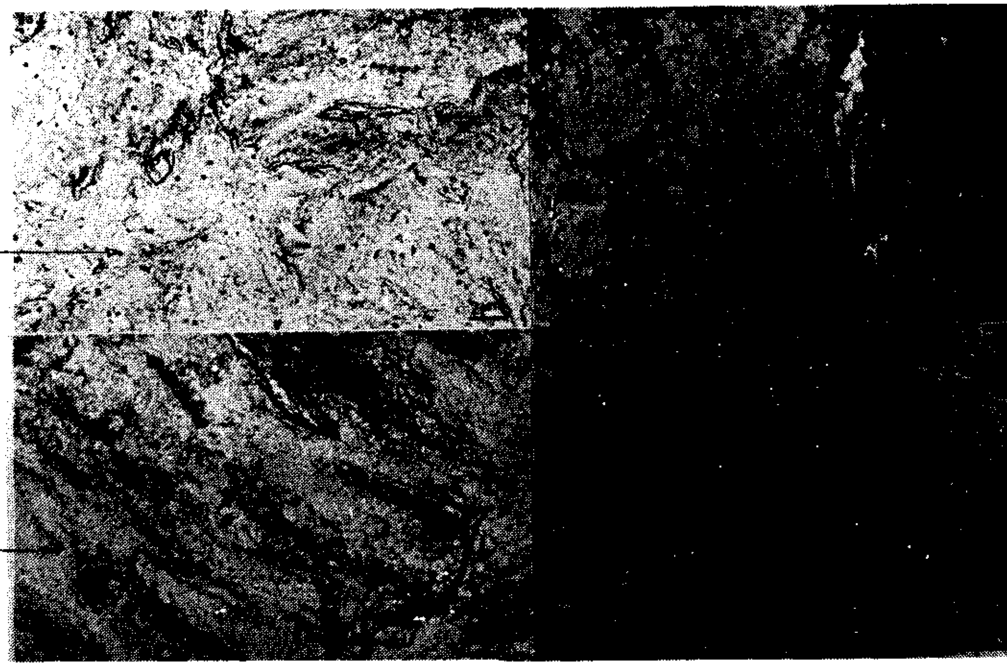


Fig. 6b

Fig. 6 The extraction replicas of fig. 5.

(a) The stress tempered specimen (1500 MPa) (page 11)

(b) The plain tempered specimen after tempering for 373 h at 200°C.

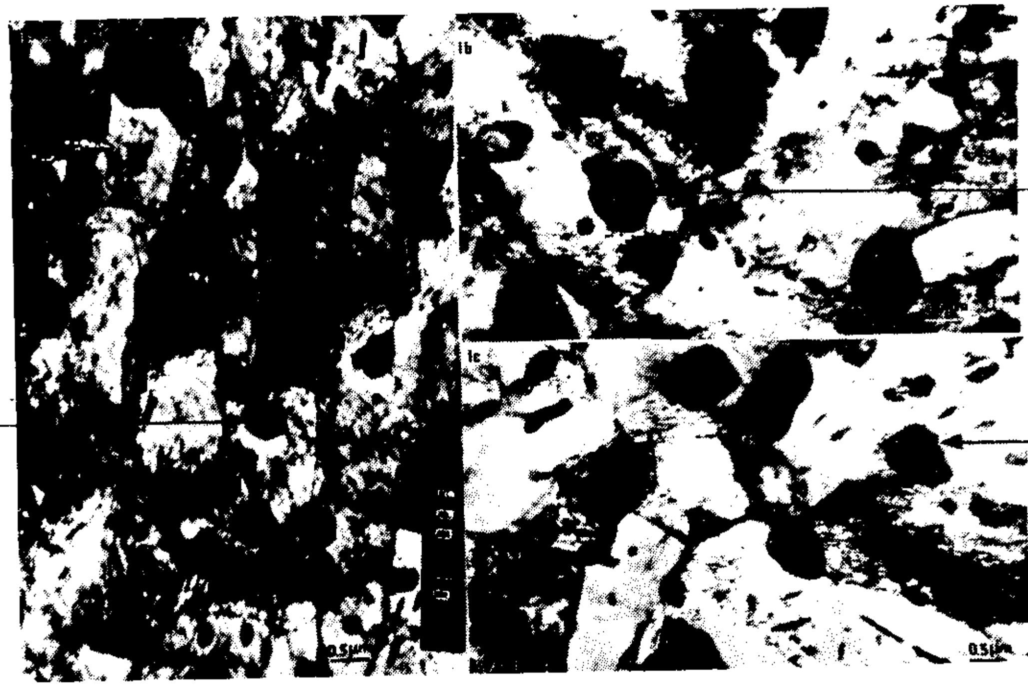


Fig. 7a

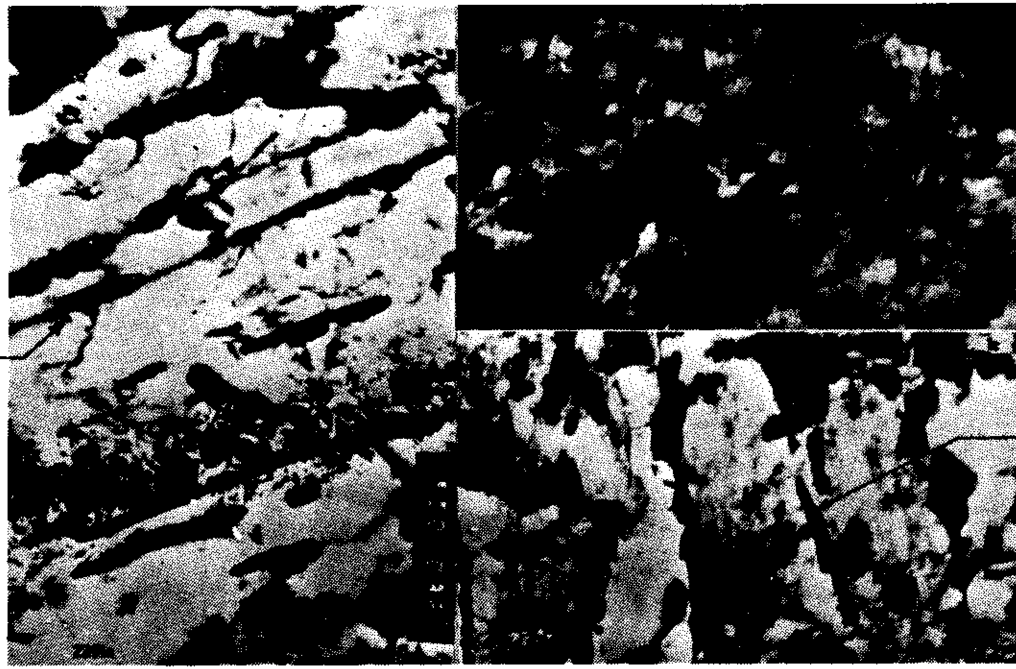


Fig. 7b

Fig. 7 The transmission electron micrograph of:

(a) The stress tempered specimen (220 MPa) (page 13)

(b) The plain tempered specimen, after tempering for 144 h at 600°C.

Showing the evidence of globularization of carbide particles after tempering under stress.

Acknowledgements

The author wishes to express his gratitude to Prof. Dr. Ir. A. Deruyttere and Ir. P. Ovaere for their interest in the work, to authorities of the university of Leuven (K.U.L.) for providing facilities for his work and to Ing. R. de Vos for technical assistance.

The author would like also to thank the Algemene Bestuur voor Ontwikkelings-samenwerking (ABOS) for the granting of fellowship during the tenure of this work.

REFERENCES

1. Gupta, VP., Dhar, PR., JISI, 1963. *202*, 213 – 216.
2. Howes, MAH., Proceedings of an Int. conf. on heat treatment, London, 1977.
3. Miller, MF., Breyer, NN., Trans. ASM, 1969, *62*, 891 – 901.
4. Morries, DG., Harries, DR., Met. Sci, 1978, *11*, 542 – 549.
5. Ridal, KA., Quarell, AG., JISI, 1962, 366 – 373.
6. Sarrak, VI et al, Fiz. Metal. Metalloved, 1976, *41*, (2), 419 – 421.