MATERIAL, HEAT TREATMENT AND ITS QUALITY CONTROL FOR MAAG TURBO GEARS (ABSTRACT)

by

Dr. P. Brezina

1 Introduction

The different stresses which occur in the gear teeth under load were explained in the paper given by W. Nägeli. The loading is concentrated to the surface. In order to increase the load carrying capacity and to improve the resistance against wear, heat treatment processes were developed. See glossary on page 5.

Schematic comparison of the 4 main processes: Fig. 1

The main principles are:

- change of properties: whole section - surface
- residual compression stresses in the surface layer
- change of chemical composition in the surface layer

2 Quenching and Tempering

Steels: min. 0,2% C

many grades, e.g. DIN 17200: 9 unalloyed types
17 alloyed types

Principle: Fig. 2

- Quench-hardening: new microstructure, hard
- Tempering: lower hardness with improved ductility

Most important parameters:

- Equivalent heat treatment diameter
- Tempering temperature
- Grade of steel Fig. 3

3 Shell hardening

Steels: C = 0,3 - 0,6%

Principle: Fig. 4

Quenched and tempered base material
only the surface is heated by means of:
electrical induction flame followed by

subsequent quenching

Results:

higher hardness in the surface layer — Fig. 5
residual compression stresses in the surface layer
(compensated by tensile stresses in the core)
thick hardened layers are produced economically,
e.g. 3mm

3 Nitriding

Steels: Two groups are used for gears:
- nitriding steel grades with Cr, Mo and V
- Steel grades for quenching and tempering

Principle: — Fig. 6

Nitrogen is introduced into the surface layer
low heat treatment temperature (approx. 500 - 570°C)
without quench-hardening
nitrogen is effective as solid solution and as
precipitate, e.g. nitride
long holding time process, therefore relatively thin
layers, e.g. 84 h result in approx. 0.4 mm

Results: — Fig. 7

high nitrogen content in the surface layer
high hardness " " " "
residual compression stress " "
relatively brittle and suceptible to impact loading
limited case depth limited modulus
limited loading

4 Case hardening

Steels: Carburizing steels with about 0.2% C

many grades available

Table 1: Examples of carburizing steels

Type		Chemical composition, % C	Mn	Cr	Ni	Mo	Rm, N/mm² 250 mm Ø
AISI	8620	.20	.75	.50	.55	.20	600
DIN	16 MnCr 5	.16	1.15	.95	-	-	630
MAAG	10 NiCrMo 7	.10	.50	.55	1.9	.60	650
AISI	4320	.20	.55	.50	1.8	.25	650
-	14 NiCr 14	.14	.55	.75	3,5	-	700
DIN	15 CrNi 6	.15	.50	1.55	1.55	-	750
DIN	17 CrNiMo 6	.17	.50	1.65	1.55	.30	930

The comparison of the Jominy test results show that the lower alloyed grade is not suitable for gears with thick cross sections. Fig. 8

Principle: Fig. 9

- Carburizing
  Carbon is introduced into the surface layer (e.g. 0,8%C) high heat treatment temperature (e.g. 940°C)
- Intermediate annealing for:
  low hardness for machining operation if necessary
  transformation of the microstructure
- Quench-hardening
- Low temperature annealing for stabilisation

The following processes were developped at MAAG by U. Wyss:

CARBOMAAG I : carburizing

CARBOMAAG II: austenitizing for quench-hardening with controlled carburizing atmosphere

Results:

similar to nitriding with the following differences:

C is introduced instead of N
quench-hardening leads to distorsion
thick layers are produced economically (e.g. 2,5 mm)

6 Comparison of the 4 processes

Hardness versus depth — Fig. 10

Endurance limits for pitting — Fig. 11
taken from DIN 3990/5 = ISO 6336/5
within the fields for each process group there are
differences as to:
steel grades
process variations
quality levels

The case hardened gears have the highest strength if the following conditions are fulfilled:
higher alloyed steel grade
highest quality level

The high quality level at MAAG enables the optimum use of case-hardened steels for high-speed gears.

7 Quality control

For all processes important for optimum results

Independent from the individual heat treatment process the following control work is applied to all main pieces of the MAAG gears:

- chemical composition
- heat identification

- ultrasonic control (inner quality)
- hardness tests on several positions on the work piece (uniformity of properties)
- visual control (surface quality)
- mechanical properties of the base material
- magnetic particle test (surface quality, cracks)

Additional control work on case-hardened gears:

- test piece in the same heat treatment cycle for the case depth
- surface hardness measurement on the tooth flanks:
  after final heat treatment
  after final machining

  With an EMCO device the hardness is measured directly on the flanks by means of a load of 62 kg.
  This method gives results similar to the Rockwell-C test. The good correlation was proved by a great number of comparative measurements.

8 Remarks to the corrosion resistance

During the last years in a few cases very small corrosion pits occurred prior to commissioning, in service or during shut-down periods.

In cooperation with the EMPA (Swiss Federal Institute for Material Testing) a great number of corrosion tests were carried out.

The results show that variations of the relatively low alloy contents within the group of case-hardening steels is of minor importance.

The additives in the lubrication oil grades, however, have a great influence on the production of the corrosion pits.

Some definitions according to
"Multilingual Glossary of Heat Treatment Terminology",
General Editor: E. Tyrkiel,
The Institute of Metals, London 1986

case,
or total diffusion layer

Complete outer region of an object within which the composition has been changed as a result of thermochemical treatment.

case hardening

Carburizing (or carbonitriding) followed by quench-hardening treatment.

quench-hardening treatment
or quench hardening
or transformation hardening

Heat treatment comprising austenization followed by cooling under conditions such that the austenite transforms more or less completely into martensite and possibly into bainite.

surface hardening

Any treatment designed to render an object significantly harder.

shell hardening

Quench-hardening treatment in which austenitizing is restricted to the surface layer of the object.

direct hardening

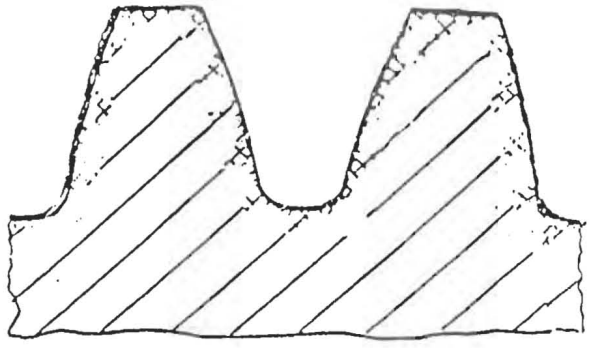
Quench-hardening of an object involving direct quenching.

direct quenching

Quenching of an object directly after a thermochemical treatment.

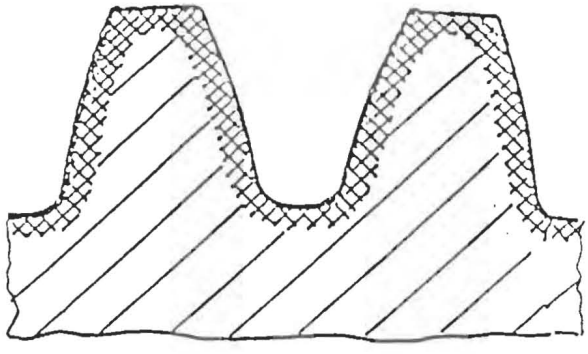
nitriding

Thermochemical treatment involving the enrichment of the surface layer of an object with nitrogen.



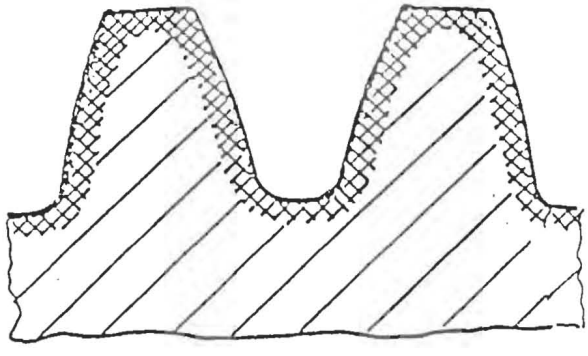
quenching & tempering

– –



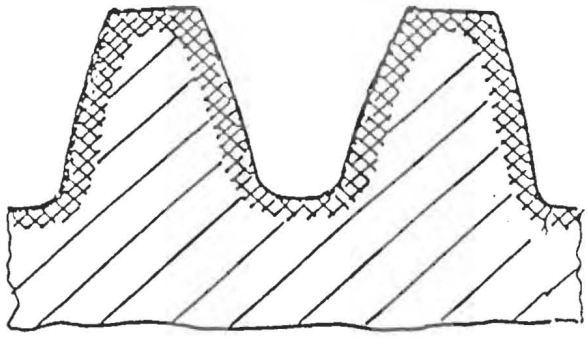
shell hardening

– σ



nitriding

$+N_2$ σ

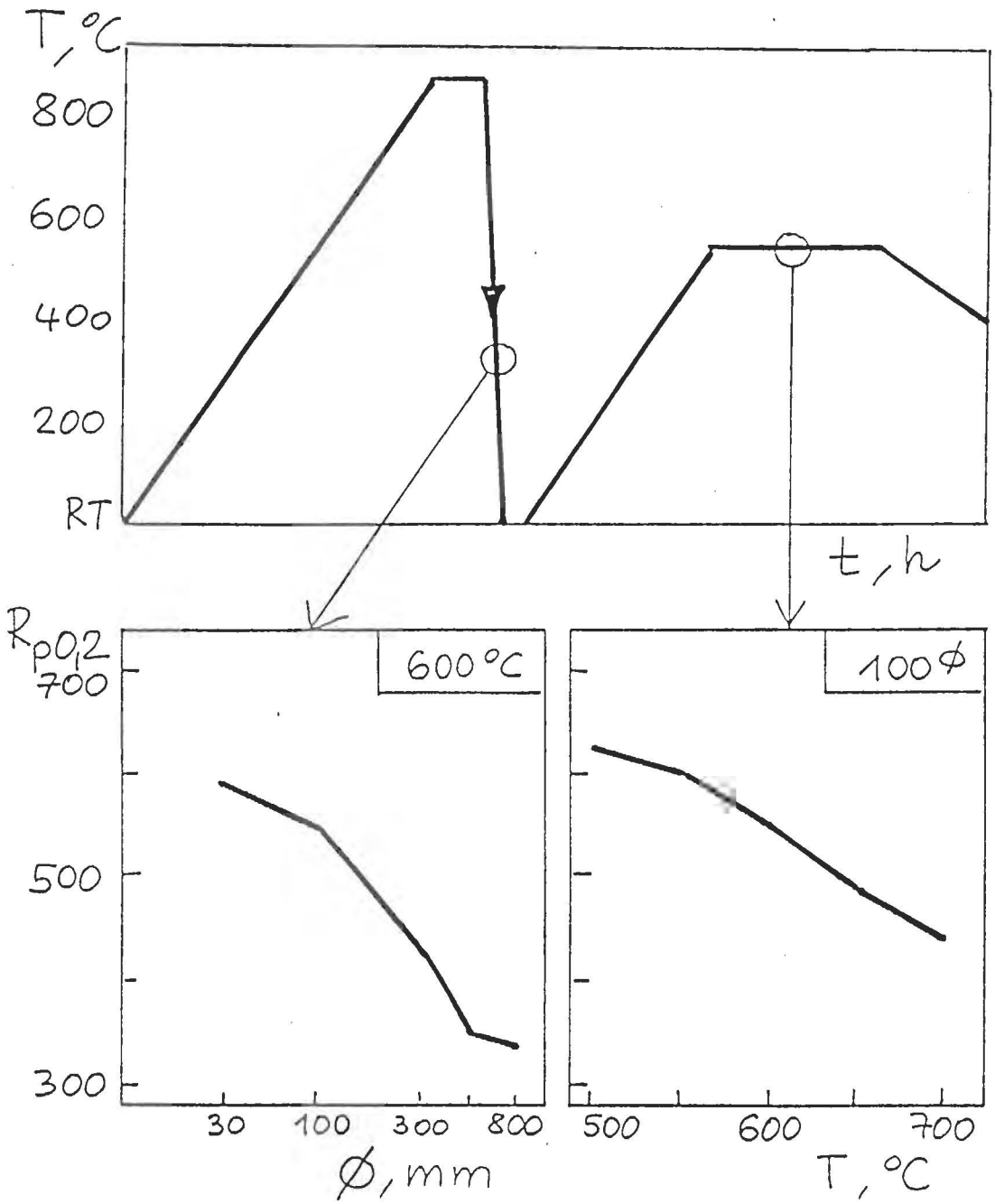


case hardening

+C σ

Fig. 1

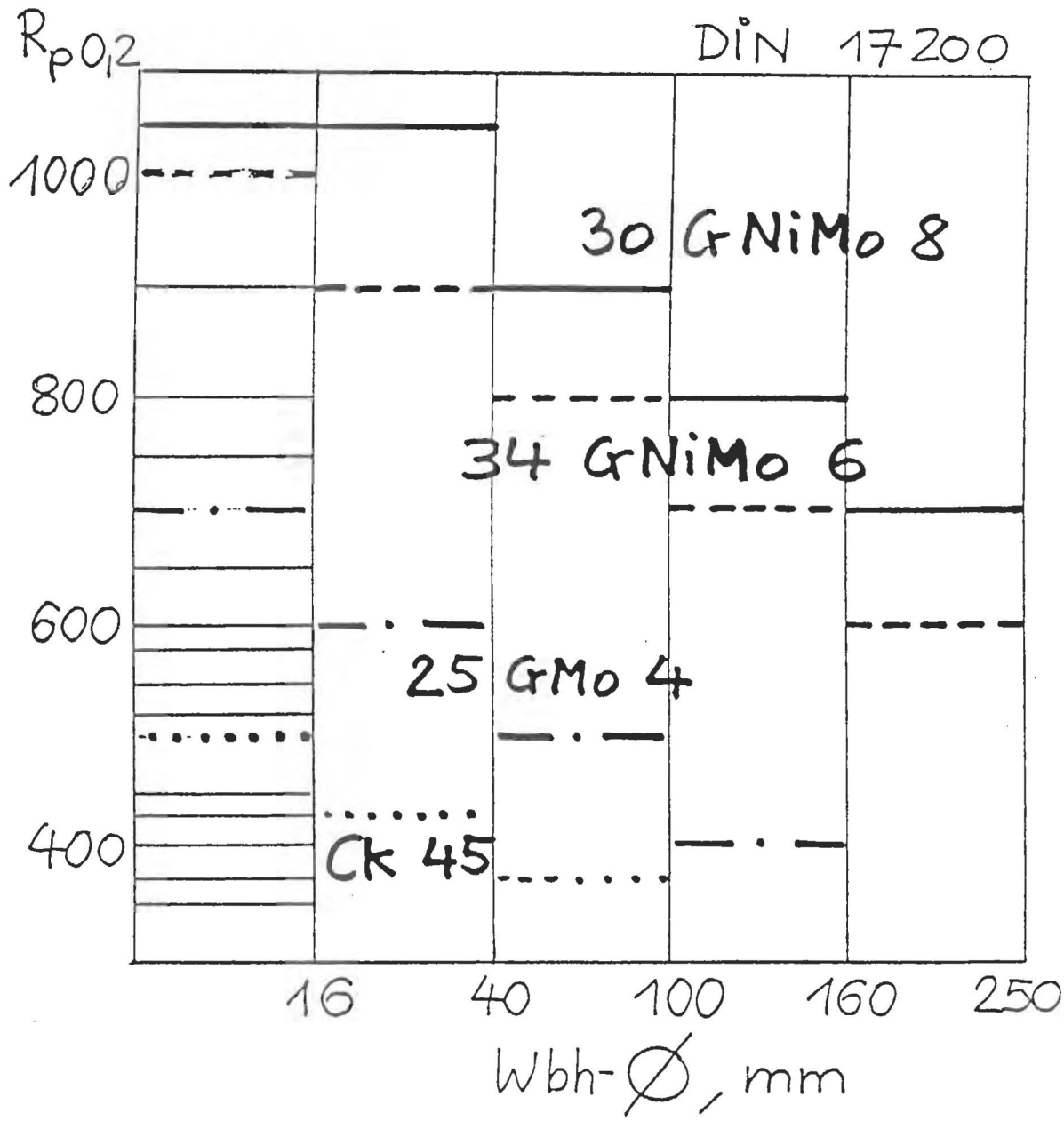
Quenching and tempering



/Hengerer, 1970/
steel 34 CrMo 4
100 mm Ø / 600 °C 4 h

Fig. 2

Quenched and tempered



Diameter at heat treatment

Fig. 3

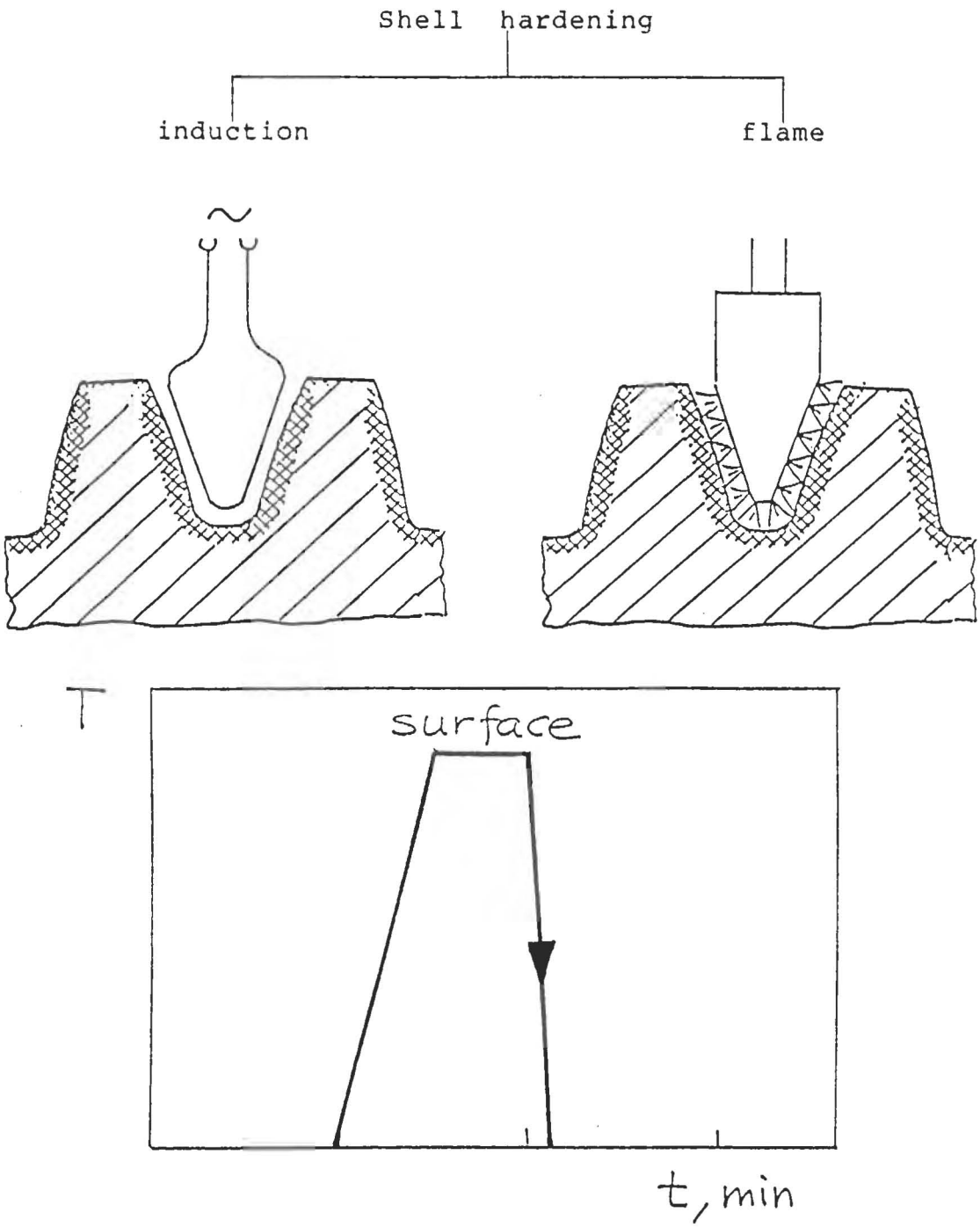


Fig. 4

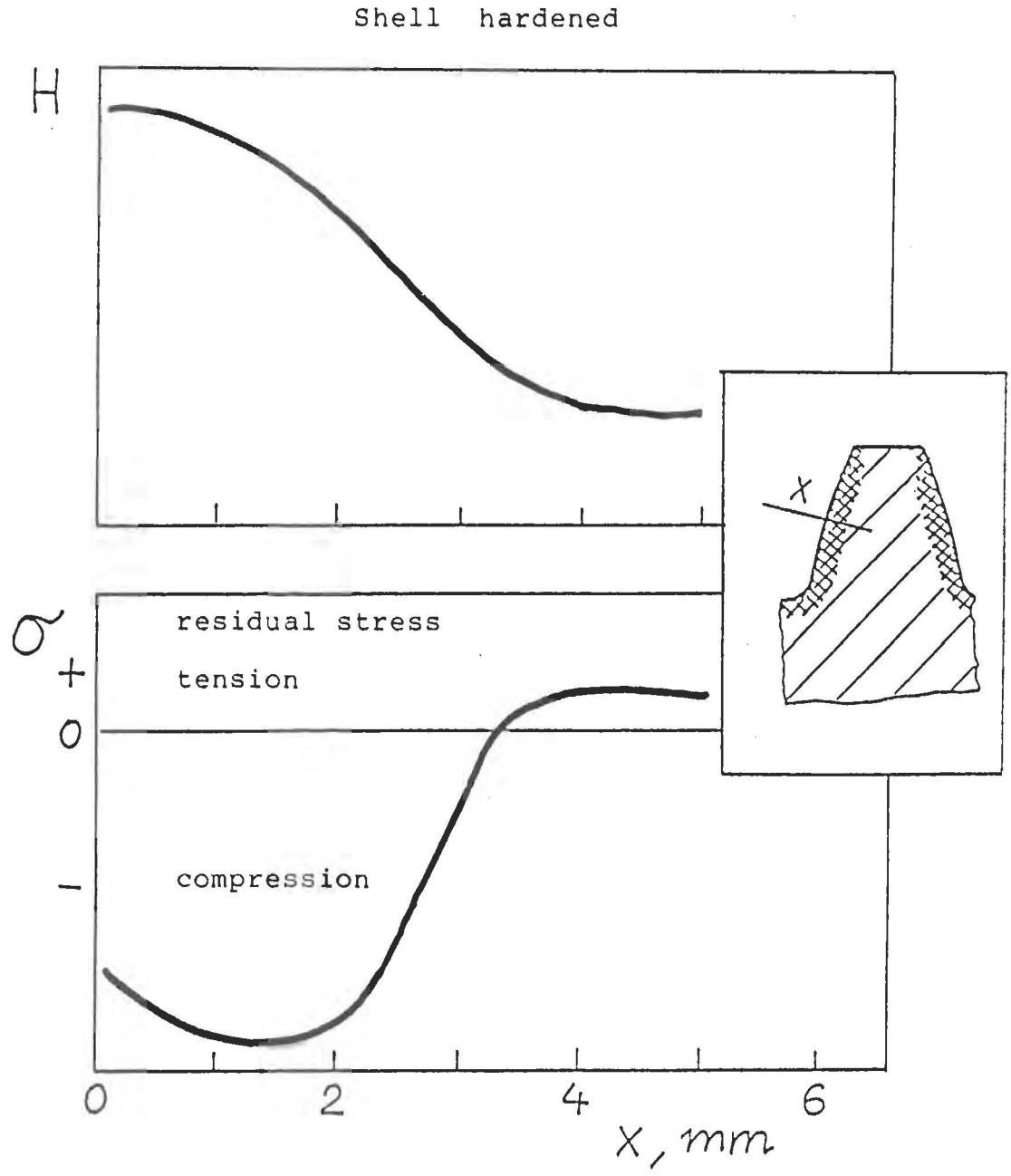
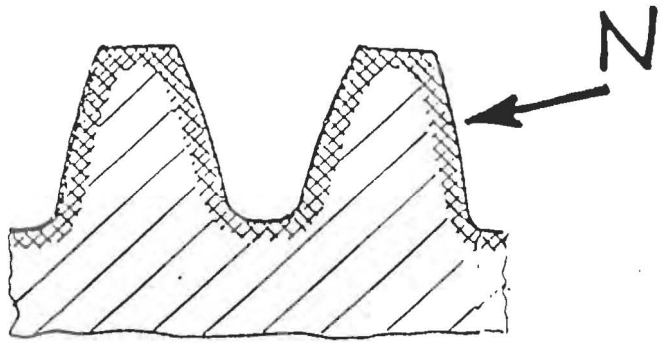

Shell hardened
H
x
σ
+
0
−
residual stress
tension
compression
0
2
4
6
X, mm

Fig. 5

Nitriding



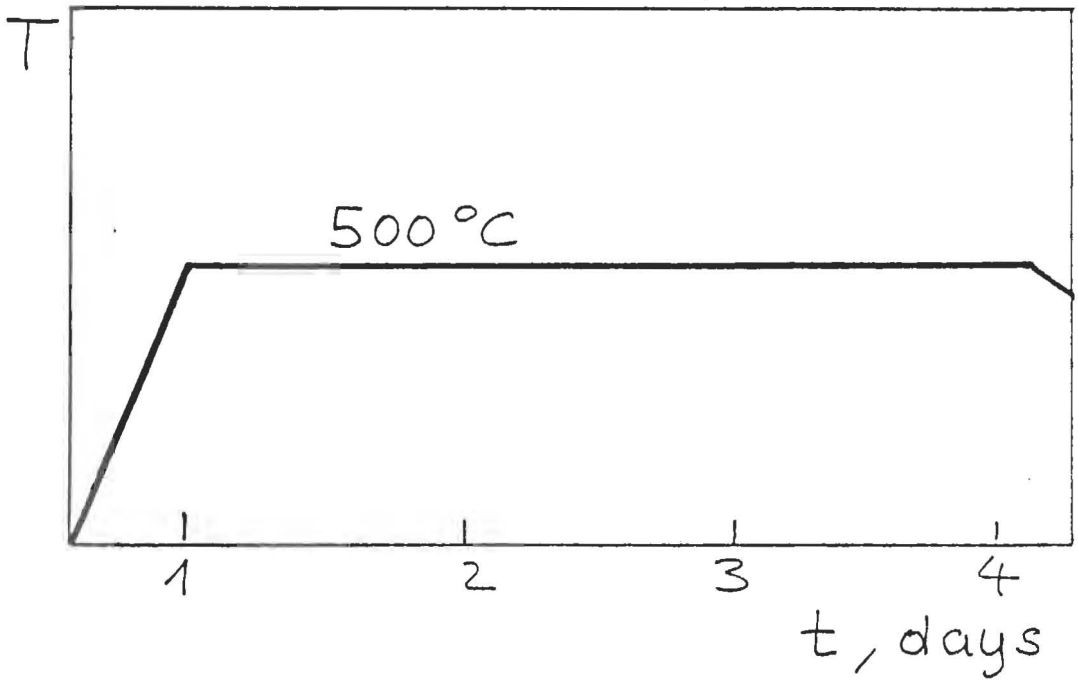


Fig. 6

Nitrided

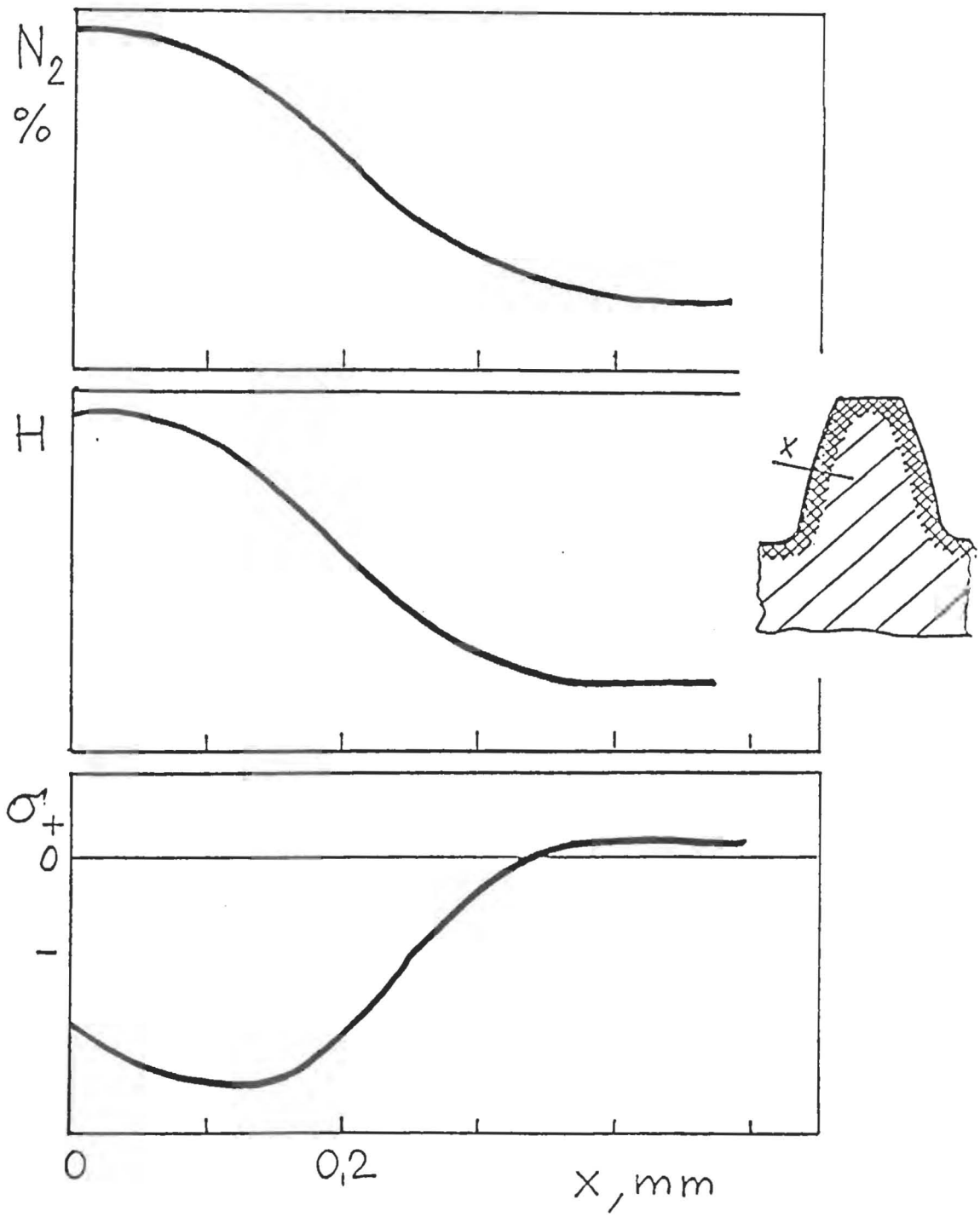


Fig. 7

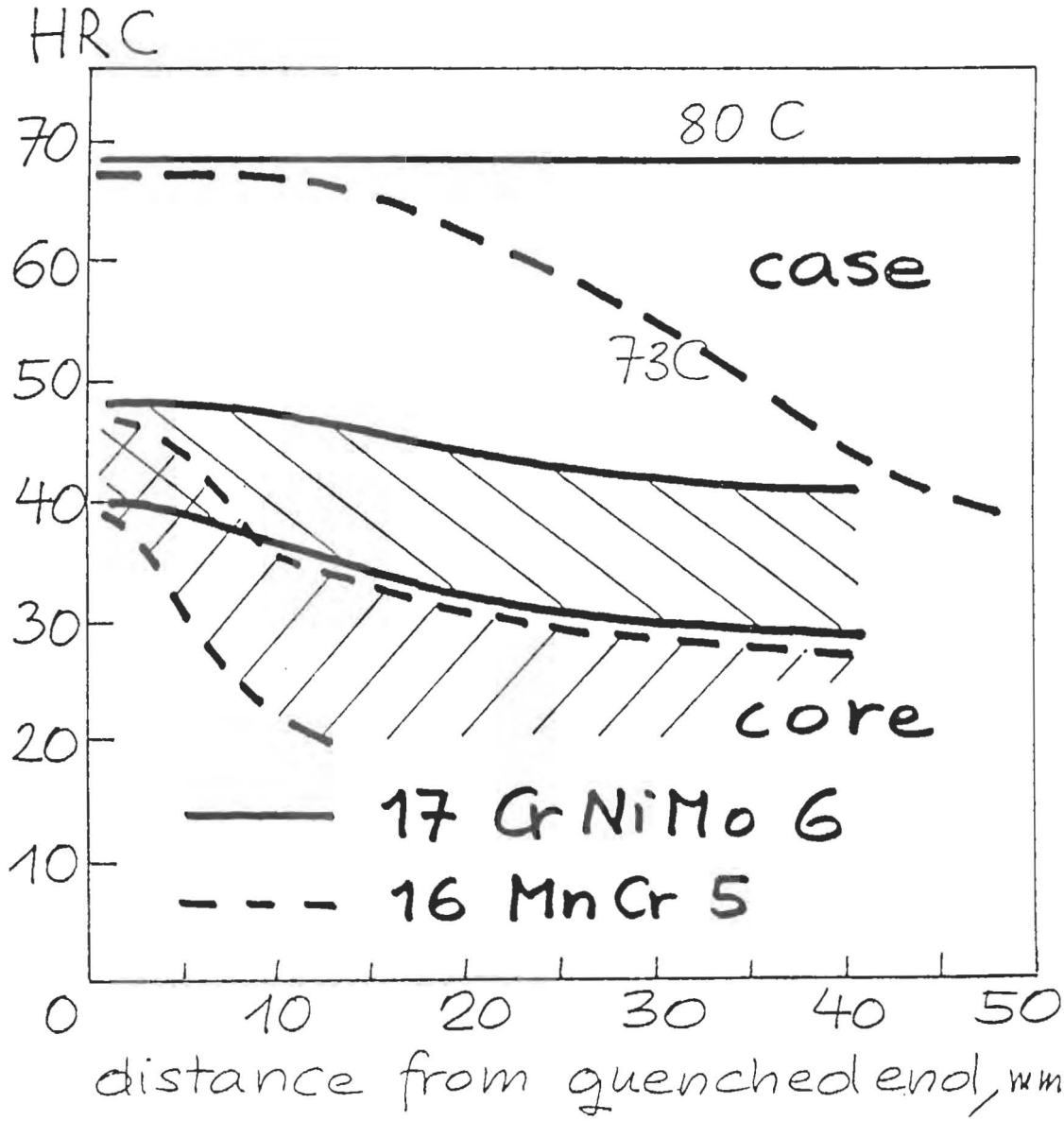
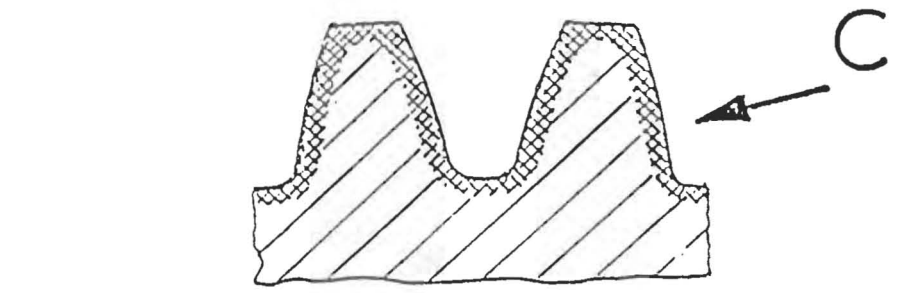
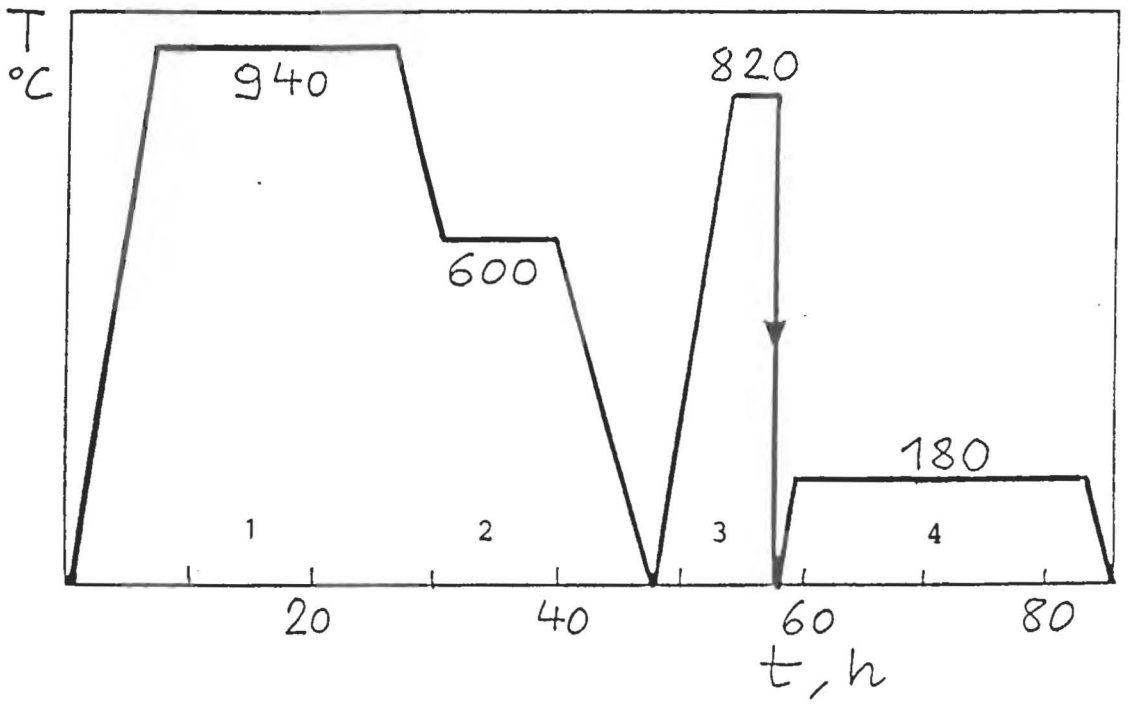

HRC
70
60
50
40
30
20
10
0
10
20
30
40
50
80 C
73C
case
core
17 CrNiMo 6
16 MnCr 5
distance from quenched end, mm

Fig. 8

Case-hardening





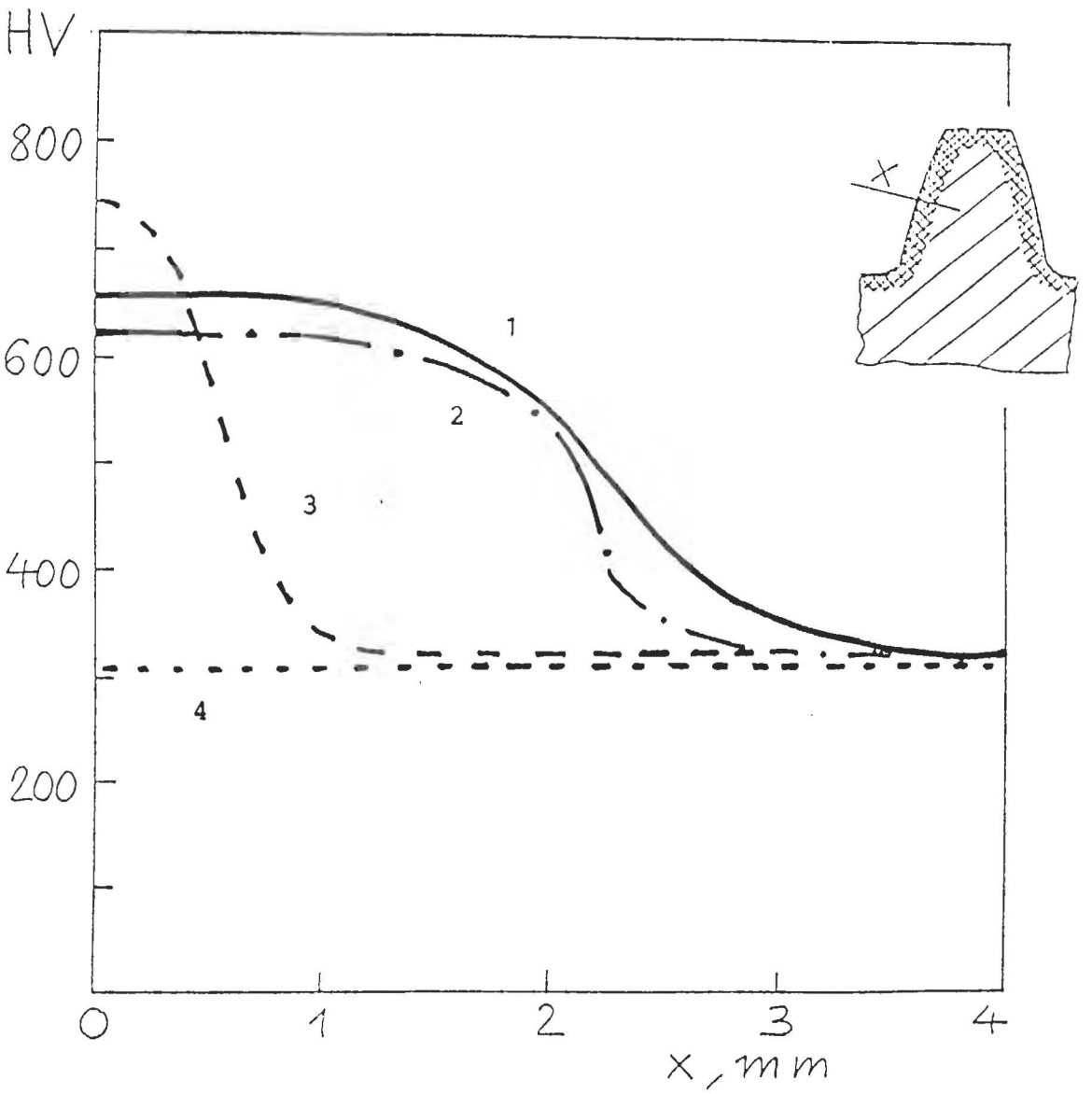
1 ..... carburizing

2 ..... intermediate annealing

3 ..... hardening

4 ..... annealing

Fig. 9



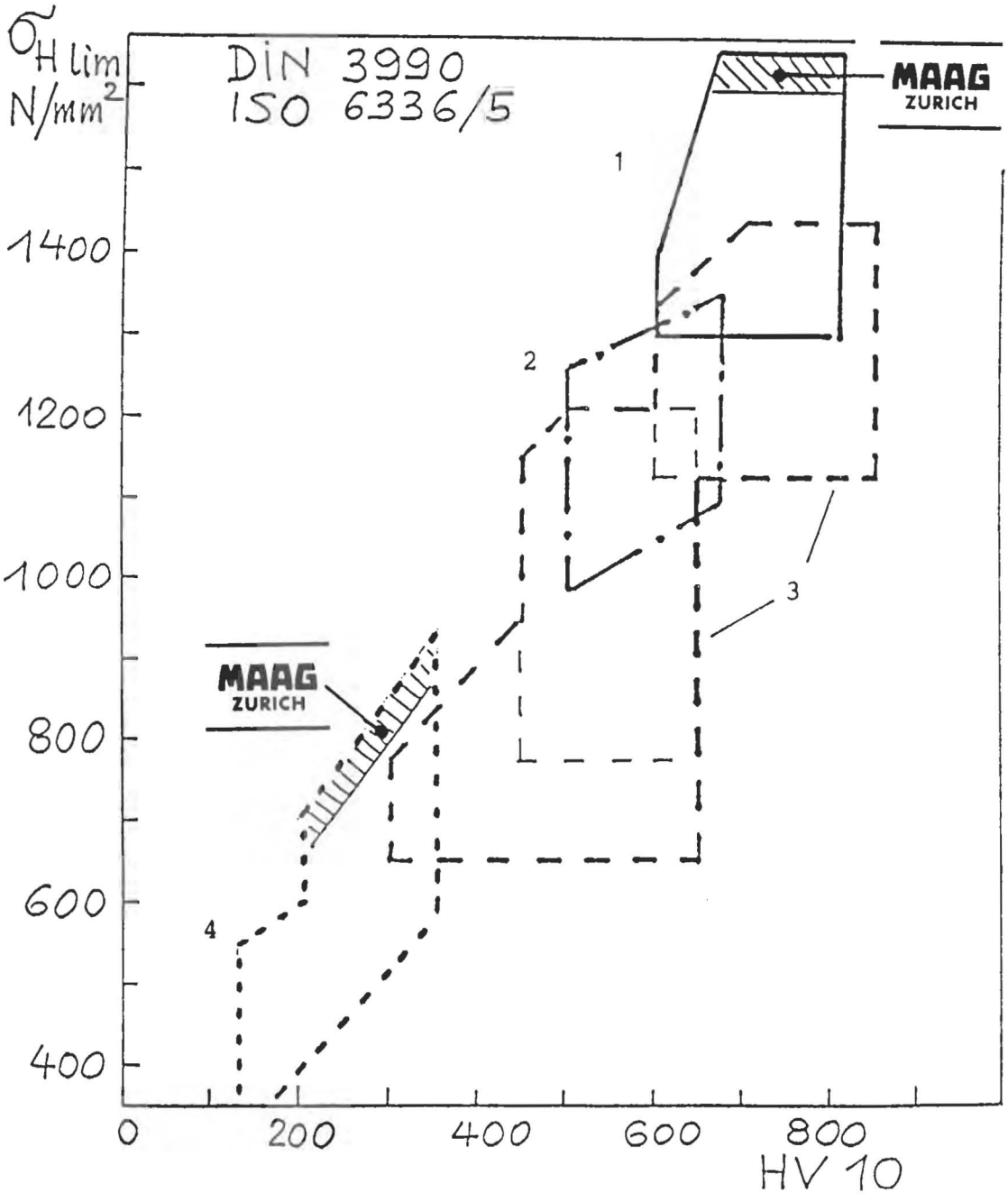
1 ..... case-hardened

2 ..... shell hardened

3 ..... nitrided

4 ..... quenched and tempered

Fig. 10



1 ..... case-hardened
2 ..... shell hardened
3 ..... nitrided
4 ..... quenched and tempered

Fig. 11