Eng. Research Bull.
Faculty of Eng. & Tech.,
Menoufia University
Vol. VII Part II, 1985.

PP. 133-148.

EFFECT OF METALLURGICAL AND GEOMETRICAL PARAMETERS ON THE DEFORMATION RESISTANCE AND WORK OF DEFORMATION DURING HOT ROLLING OF SINGLE-AND TWO-PHASE BRASSES

A. R. EL-DESOUKY*

ABSTRACT:

The solution of all technological problems of metal working required information about the behaviour of material during plastic deformation.
The mean deformation resistance K_m and the specific work of deformation W_s are considered to be the most important measurable values during hot rolling.
In this work, K_m and W_s were experimentally determined and an attempt was made to correlate these values with: microstructure, phase and didfferent geometrical values for single-phase α -brass (70 Cu - 30 Zn) and two-phase $\alpha + \beta$ brass (60 Cu - 40 Zn).
The strain rate and rolling temperature were kept constant at 10 s^{-1} and 550°C respectively.

It was found that K_m and W_s, for constant specimen thickness, increased with the amount of deformation ε . In the examined range of ε (up to 50 % per pass) no decrease in K_m due to dynamic softening was observed.
At a constant ε; K_m and W_s showed a minimum with l_d/h_m then increased again. The results indicate that two-phase brass has a higher deformation resistance and work of deformation compared with single-phase brass.

---

* Lecturer, Department of Design and Producting Engineering, Faculty of Engineering and Technology, Menoufia University.

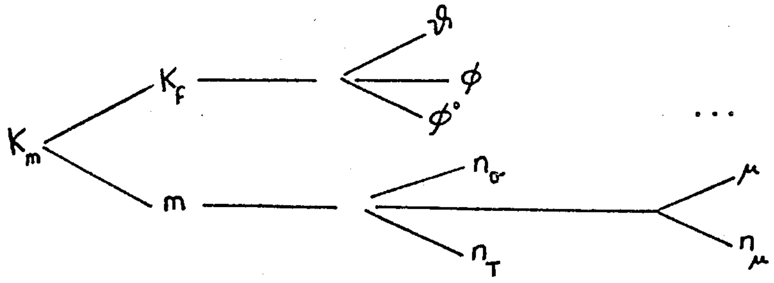
An explanation was given to declare the above results.

NOMENCLATURE:

K_m	mean deformation resistance	MPa
W_s	specific work of deformation	J/mm^3
ϕ	true strain	
ϕ°	true strain rate	s^{-1}
h_o	initial height of specimen	mm
h_f	final height of specimen	mm
Ω	rolling temperature	^{o}C
K_f	constrained flow stress	MPa
Δh	reduction in height	mm
$\varepsilon\%$	$(h_o - h_f) / h_o \,.\, 100$	
h_m	mean height of specimen	mm
R	roll radius	mm
b_o	initial } width of specimen	mm
b_m	mean	
b_f	final	
l_d	projected length of the arc of contact $=\sqrt{R.\ \Delta h}$	mm
A_d	area of deformed zone $= b_m \,.\, l_d$	

INTRODUCTION:

The basic factors affecting K_m can be summarised as follows:



... ... (1)

Where;

m - a general function.
n_σ - stress distribution factor depending upon geometry of deformed zone.
n_T - front or backward tension (external force acting on the deformed metal at the entry of deformation zone).
μ - friction coefficient.
n_μ - influence of the parts of the metal outside the deformation zone.

A general solution of this function does not exist at the moment in the theory of plastic deformation. There are several particular solutions adapted to the specific process under study. The most popular appoach, mainly for rolling, is the plane strain condition /1/.

According to Nadai /2/, the effect of the above mentioned factors on K_m can, in the general case, be expressed as:

$$dK_m = \frac{\partial K_m}{\partial \theta} d\theta + \frac{\partial K_m}{\partial \phi} d\phi + \frac{\partial K_m}{\partial \phi^\circ} d\phi^\circ + \frac{\partial K_m}{\partial t} dt \quad \dots \quad \dots \quad (2)$$

where the fourth item of equation 2 considers the relaxation with the time t. The total work W required to produce a shape by plastic deformation can be divided into a number of components. The work of deformation W_d is the work required for homogeneous reduction by uniform deformation. Often, part of the total work is expended in redundant work W_r. The redundant, or internal - deformation, work is the energy expended in deforming a body but not involved in shape change. Finally, part of the total work must be used to overcome the frictional resistance at the interface between the forming tool and the metal.

$$W = W_d + W_r + W_f \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3)$$

A similar equation for K_m can be writen as:

$$K_m = K_f + K_r + K_i \quad \dots \quad \dots \quad \dots \quad \dots \quad (4)$$

Where;

K_r - frictional stress at the interface between metal and tool.

K_i - redundant stress.

Fig. 1. illustrates the variation of K_r, K_i, and K_m with the geometry of deformed zone (length of deformed zone l_d/mean height h_m) at a constant K_f/3/.

The effect of metallurgical parameters (grain size, type, size and shape of phases) on the deformation resistance has been studied by several investigators.

Kaneko and Horiucki /4/ examined the effect of grain size D and distance between dendrites d on the deformation resistance of aluminium and copper alloys during hot torsion at 450°C and strain rate of 5 s^{-1}.
The following dependence was arrieved at:

$$K_m = K_o + Kd^{-1/2} + KD^{-1/2} \quad \dots \quad \dots \quad \dots \quad (5)$$

Köpf /5/ investigated the effect of chemical composition and solution heat treatment on the deformation resistance of Al-Mg and aluminium-bronzes. He considered that precipitation hardening effect is appreciated as one of the most important strengthening mechanisms which increases the deformation resistance. Heinemann /6/ found that K_m increased with decreasing rolling temperature and increasing reduction per pass during hot rolling of several aluminium and copper alloys. A similar results have been concluded by Höptner on Al & Al-Mg alloy during hot compression /7/.

In this work an attempt was made to study the effect of both parameters: metallurgical and geometrical on K_m and W_s of single-phase α - brass and two-phase $\alpha+\beta$ brass.

Since a limited experimental information is available on the deformation of two-phase alloys, it is aimed in this work to present results about the deformation resistance of single-and two-phase structure during hot working.

EXPERIMENTAL PROCEDURE:

The alloys were prepared from highly pure copper and zinc and melted under vaccum.

The chemical composition of the alloys was depicted (in wt. %) in the following table.

Alloy	Cu	Zn	Fe	Sn	Al	Mn	Pb
A	69	30.5	0.1	0.1	0.1	0.1	0.03
B	59	40	0.2	0.2	0.1	0.2	0.3

Alloy A consists mainly from single phase α while alloy B contains two-phase structure $\alpha + \beta$ as shown in the micrographs (Fig. 2) of the as-cast structure at room temperature.

Three different specimen thicknesses 10 , 20 and 30 mm, were heated in an electric resistance furnace at a temperature of 550°C for four hours.

At the rolling temperature of 550°C, the two alloys were found to have the same structures as depicted in Fig. 2.

Rolling was performed at a two-high, pull-over mill with a roll radius of 180 mm. To avoid the effect of strain rate on K_m and W_s, the experiments were carried out at a constant mean value of ϕ° equal to 10 s^{-1}. Accordingly, the number of revolutions per minute (n) have to be corrected for each reduction per pass ε and h_o in order to keep $\phi°$ constant.

$$n = \frac{\phi° . 60 . \sqrt{R . \Delta h}}{2 \pi R . \phi} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots (6)$$

Fig. 3. shows the values of n required to give constant $\phi°$ for different ε & h_o. The lower and upper rolls were constructed to be fitted with a tungesten radial pen which transmitted the pressure to a dynamometer. Signals were transmitted from dynamometer to a simple resistance amplifiers then to oscillograph.

K_m was caculated as follows:

$$K_m = F / A_d \quad \text{MPa} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots (7)$$

W_s was calculated, assuming that the exit velocity of rolled specimen equals the initial roll velocity, by the equation:

$$W_s = T / (b_m . h_1 . R) \quad J \ mm^{-3} \quad \dots \quad \dots \quad \dots (8)$$

Where T is the total torque in J.

EXPERIMENTAL RESULTS AND DISCUSSION

It was found that K_m and W_s for both A & B alloys increased with ε at a constant h_o (Figs. 4 to 7). The rate of increase of K_m and W_s was higher for a thin specimen. In the examined range of (up to 50% per pass), K_m and W_s did not decrease due to the dynamic softening mechanisms. Metallographic examination of rapidly quenched A & B specimens after different ε showed that only dynamic recovery was acting during this high temperature of deformation. The extent of recovery was higher for the two-phase structure (Alloy B) which means a retardation of recrystallisation. This result can be explained on the basis that the second phase blocks slip so that plastic deformation is not uniform in the matrix. This result was in agreement with several works on aluminium and copper alloys /8 , 9 & 10/.

A comparison of the behaviour of alloys A & B clearly demonstrates the dependence of K_m and W_s on chemical composition and consequently on grain size in addition to size, shape, number and distribution of the second-phase particle, the strength, ductility and strain-hardening behavior of the matrix and second phase. It is almost impossible to vary these factors independently in experiments.

A higher K_m - and W_s - values were reported for B alloy.

The effect of ε and h_o on K_m and W_s can be clarified by the complex interaction of the following factors:

- Strengthening of the material during deformation,
- Variation of the geometry of the deformed zond, l_d/h_m was little affected by the increase of ε for a thick specimen compared to a thin one,
- Cooling of rolled specimen, which depends upon height of specimen, amount of deformation (contact area) and number of revolutions (time of contact) Fig. 2.

Regarding the effect of the geometry of deformed zone on K_m and W_s (Figs. 4,5 & 6,7) the following points can be deduced:

At a constant ε : K_m & W_s decreased to a minimum value then increased again. This minimum has been shifted to a higher values of l_d/h_m with increasing ε .

Several works on steel showed that K_m attained a minimum at $l_d/h_m \cong 1$. An exact explanation of this result cannot be given here.

At constant h_o : Approximately linear relationships between K_m and W_s vs. l_d/h_m were found. Thin specimens have a higher rate of increase of K_m - and W_s - values.

CONCLUSION

The results of the present investigation can be summarised as follows:

1. The mean deformation resistance K_m and the specific work of deformation W_s were found to be affected by: initial height of specimen, l_d/h_m as a ratio of the length of deformed zone to the mean height of specimen, and amount of deformation.
   In addition, both the deformation resistance and work of deformation depend on the metallurgical parameters which include: chemical composition of the alloy, grain size and shape, size and distribution of α - phase in β - matrix.
2. At constant amount of deformation; the deformation resistance and work of deformation showed a minimum with l_d/h_m. While at constant initial height of specimen h_o, the curves showed a linear relation that can be ascribed by a simple mathematical equation.

ACKNOWLEDGEMENT:

The author is indebted to Prof. Dr. A. A. Nasser for his valuable discussions and encouragement throughout this research.

REFERENCES:

1. E. Thomsen, C. Yang and S. Kobayashi:
   "Mechanics of Plastic Deformation in Metal Processing",
   Mcmillan Press (1965), 373.
2. A. Nadai:
   "Theory of Flow and Fracture of Solids",
   Vol. 1, McGraw-Hill, New York (1950).

3. A. R. El-Desouky:
   Dr. Eng. Thesis, Bergakademie-Freiberg (1977).
4. J. Kaneko and R. Horiuchi:
   Aluminum, 52 (1976) 378.
5. H. Köpf
   Z. für Metallkunde 63 (1972) 9, 522.
6. H. H. Heinemann:
   Dr. Eng. Thesis, Th Aachen (1968).
7. H.-G. Höptner:
   Dr. Eng. Thesis, TU-Hannover (1968).
8. H. - P. Stüwe:
   "Deformation under Hot-Working Conditions",
   Spec. Rep. 108, Iron and Steel Inst. (1968) London.
9. Y. Ohtakara, T. Nakamura and S. Sakui:
   Trans. Iron Steel Inst. Japan 12 (1972) 3, 207.
10. H.-P. Stüwe and B. Drube:
   Z. für Metallkunde 58 (1967) 6, 499.

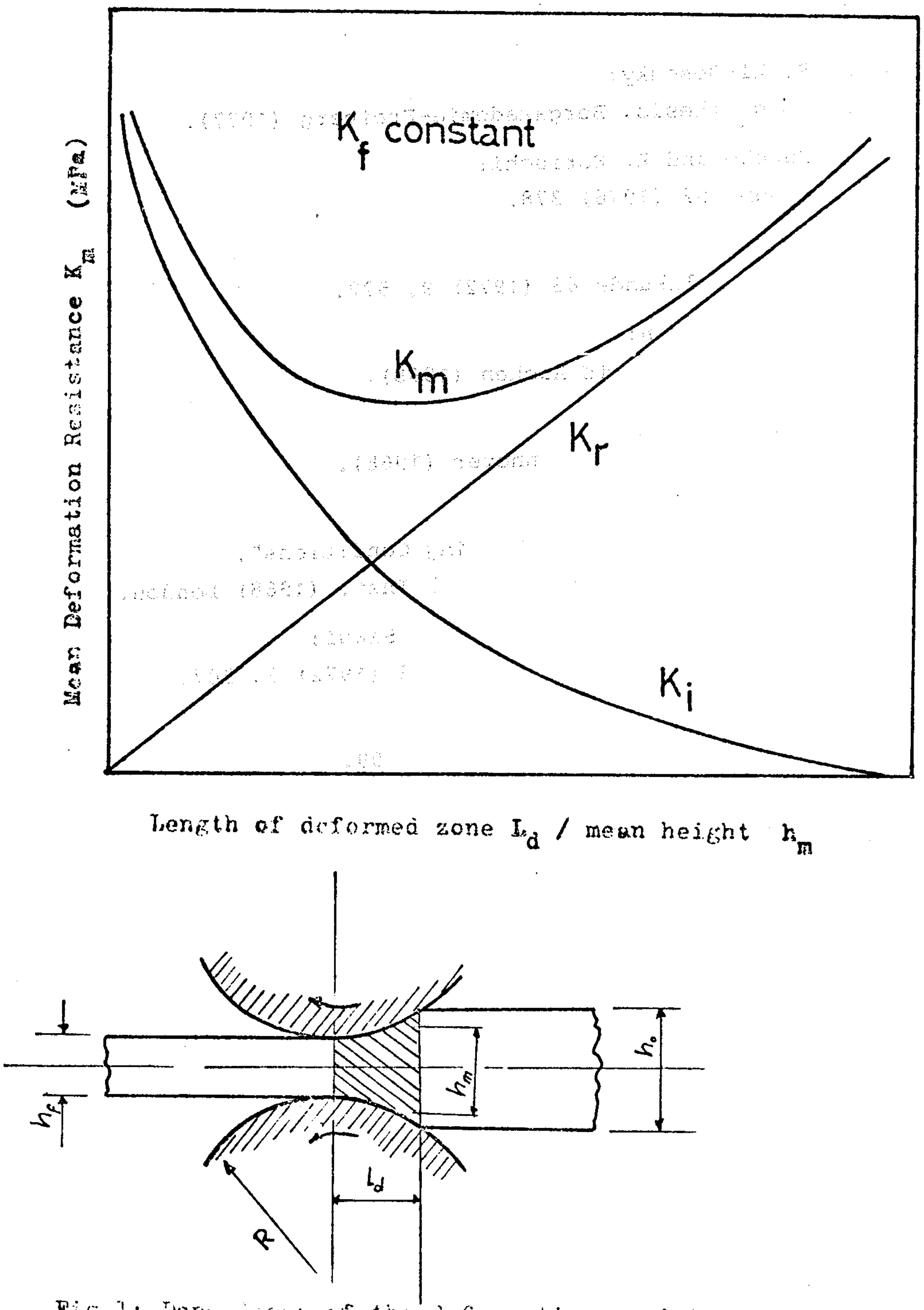
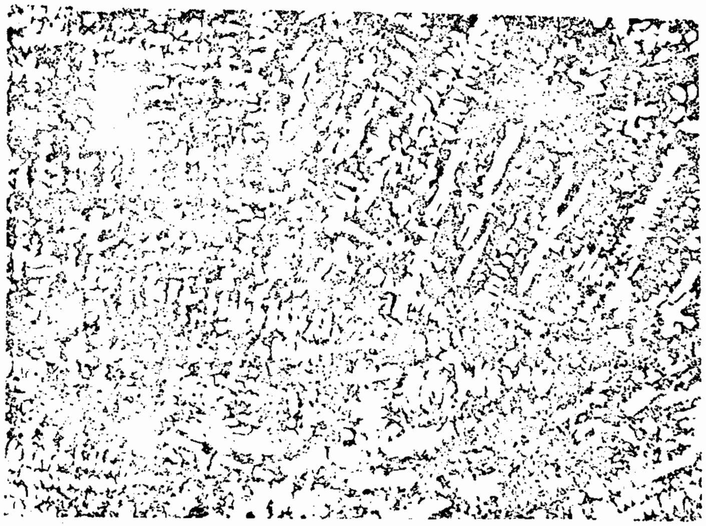
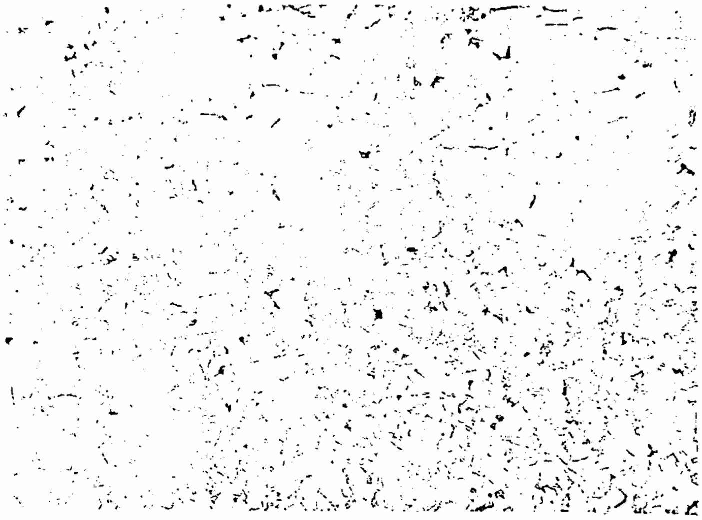


Fig.1: Dependence of the deformation resistance on the geometry of deformed zone



Alloy B



Alloy A

Fig.2 Microstructures in the as-cast condition at room temperature (400 X)

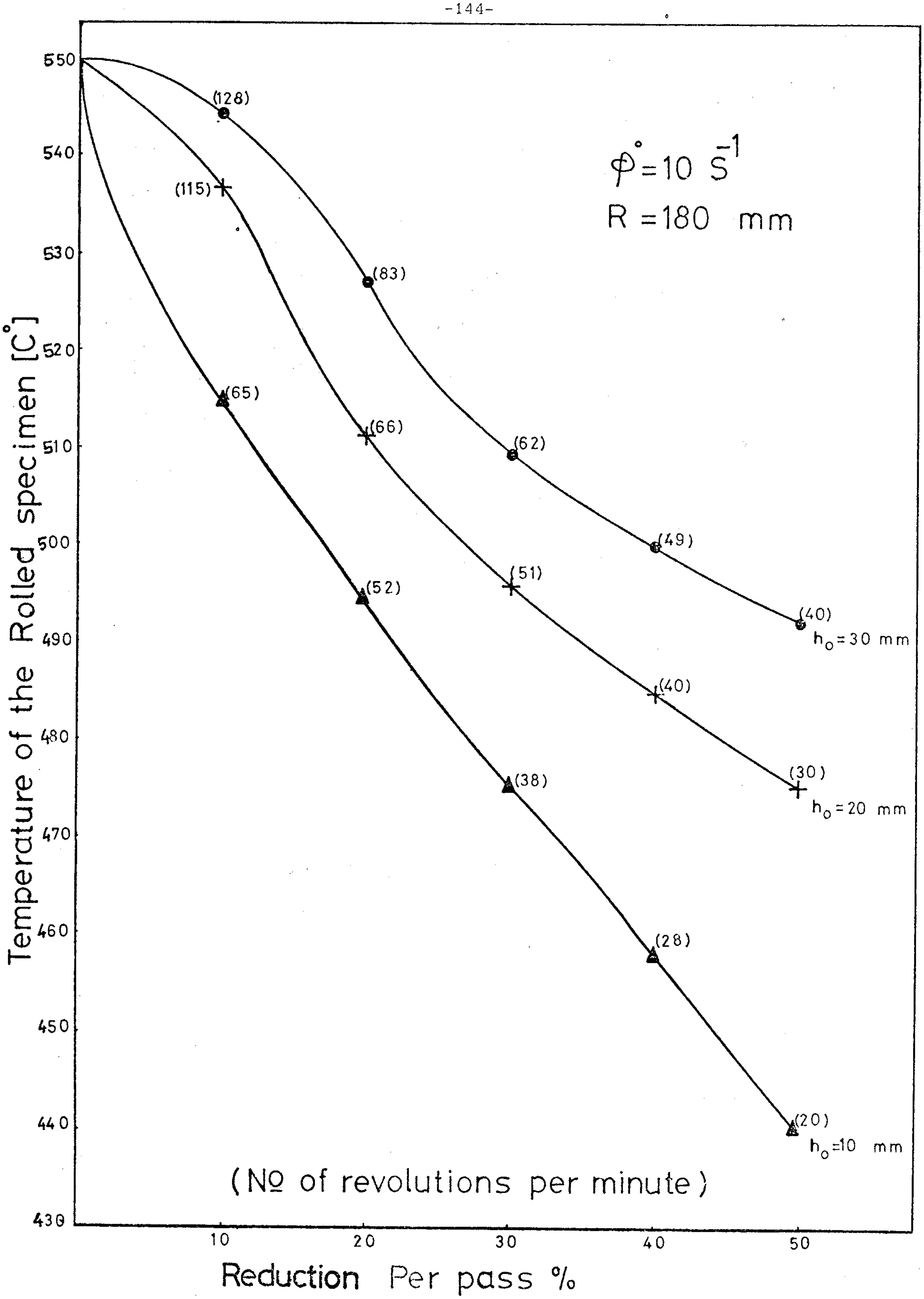


Fig.3: Temperature descent of the rolled specimen during rolling

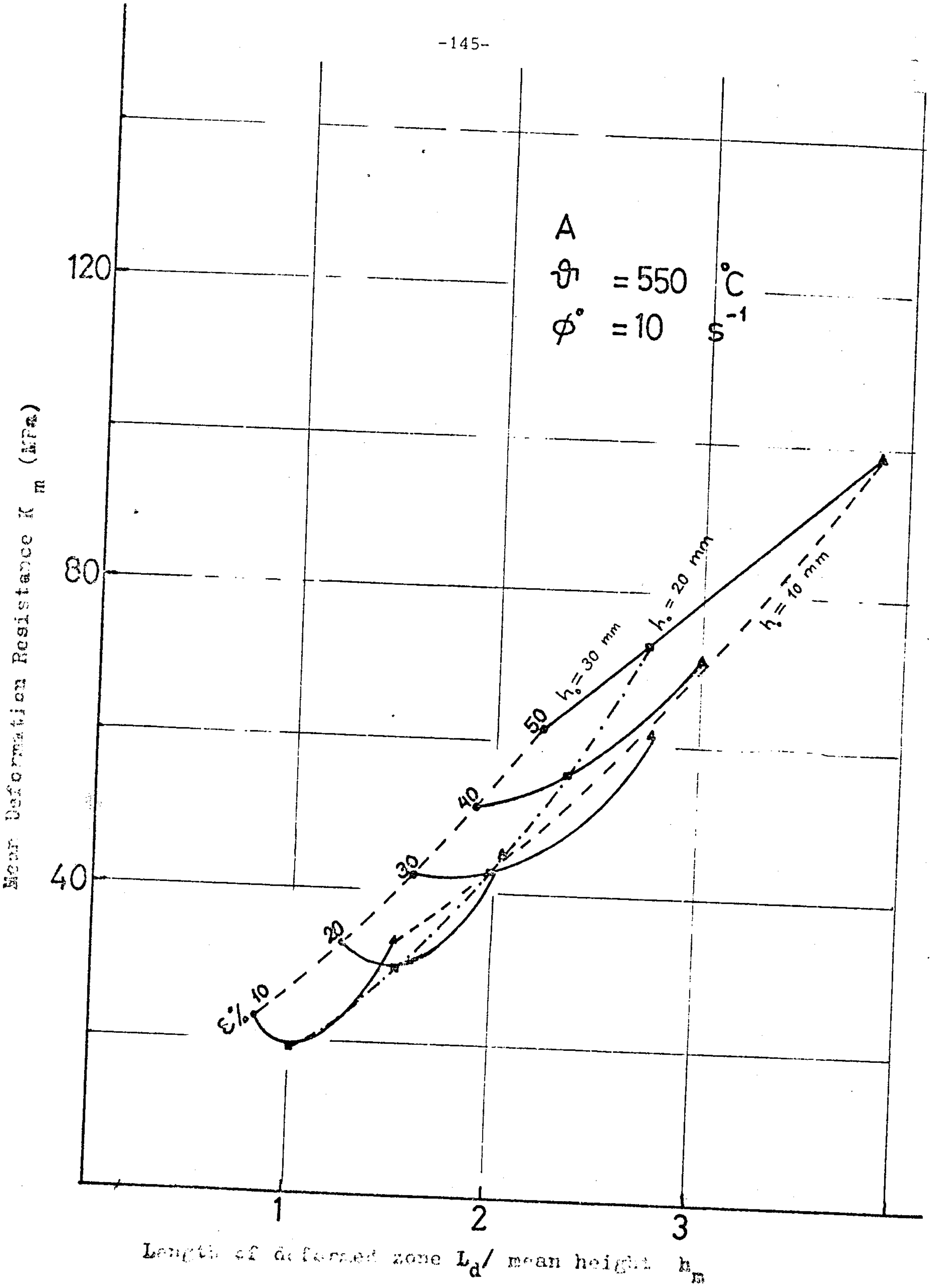


Fig.4: Dependence of K_m on L_d / h_m for different amounts of deformation ε and initial heights of rolled specimens h_o

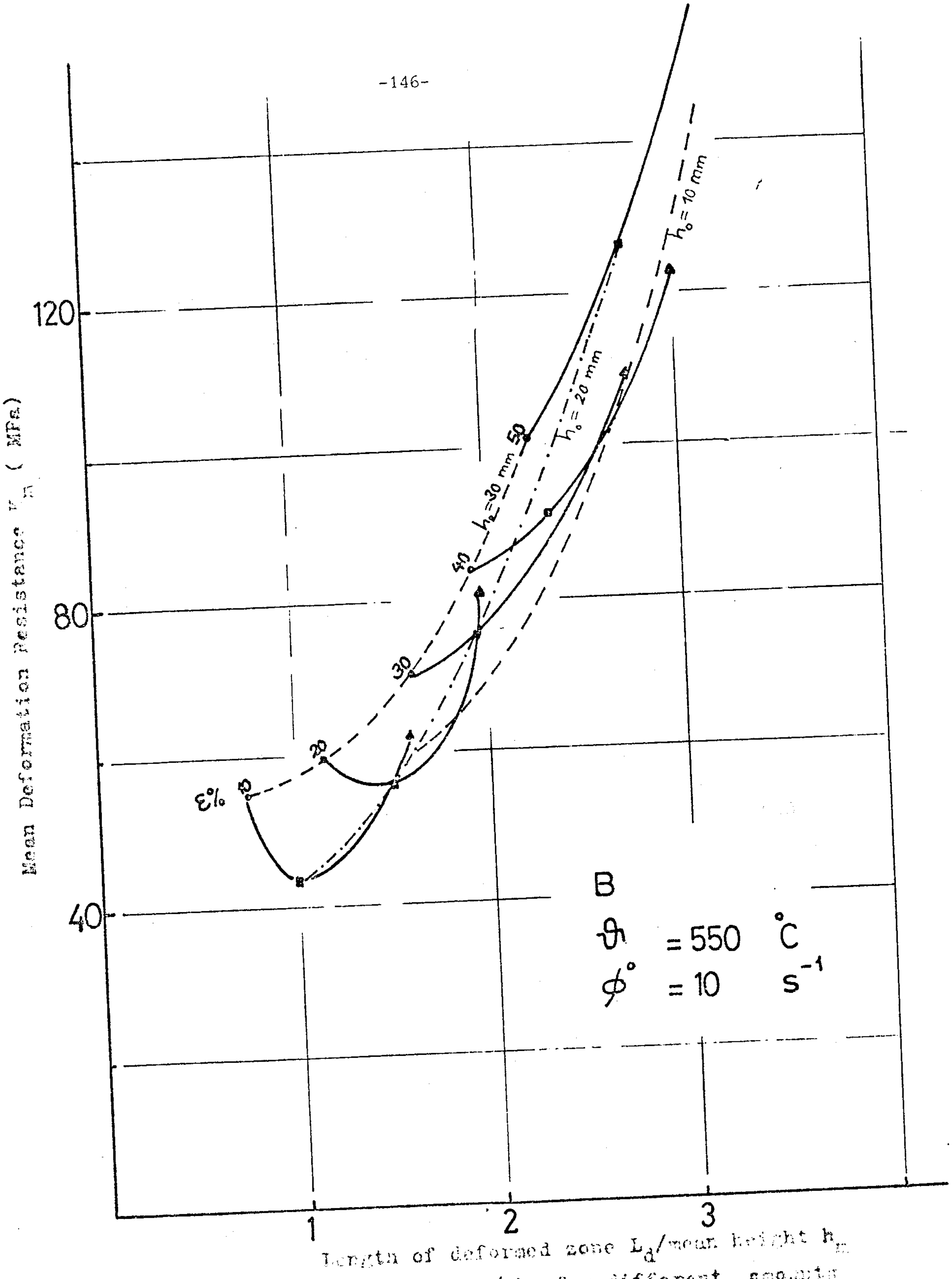


Fig.5: Dependence of K_m on L_d / h_m for different amounts of deformation ε and initial heights of rolled specimens h_o .

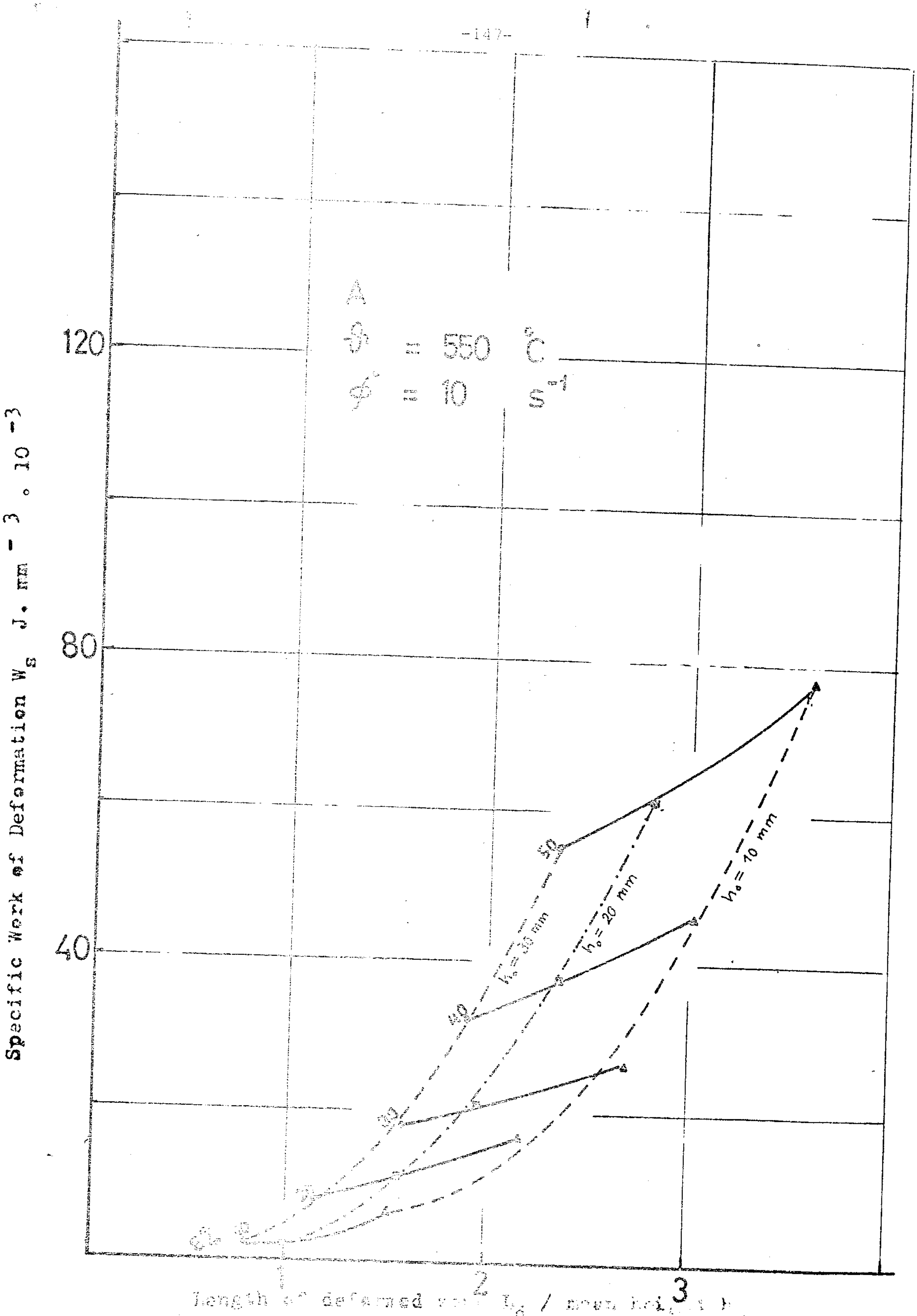


Fig.6: Dependence of W_s on L_d / h_m for different amounts of deformation S and initial height of rolled specimens h_0.

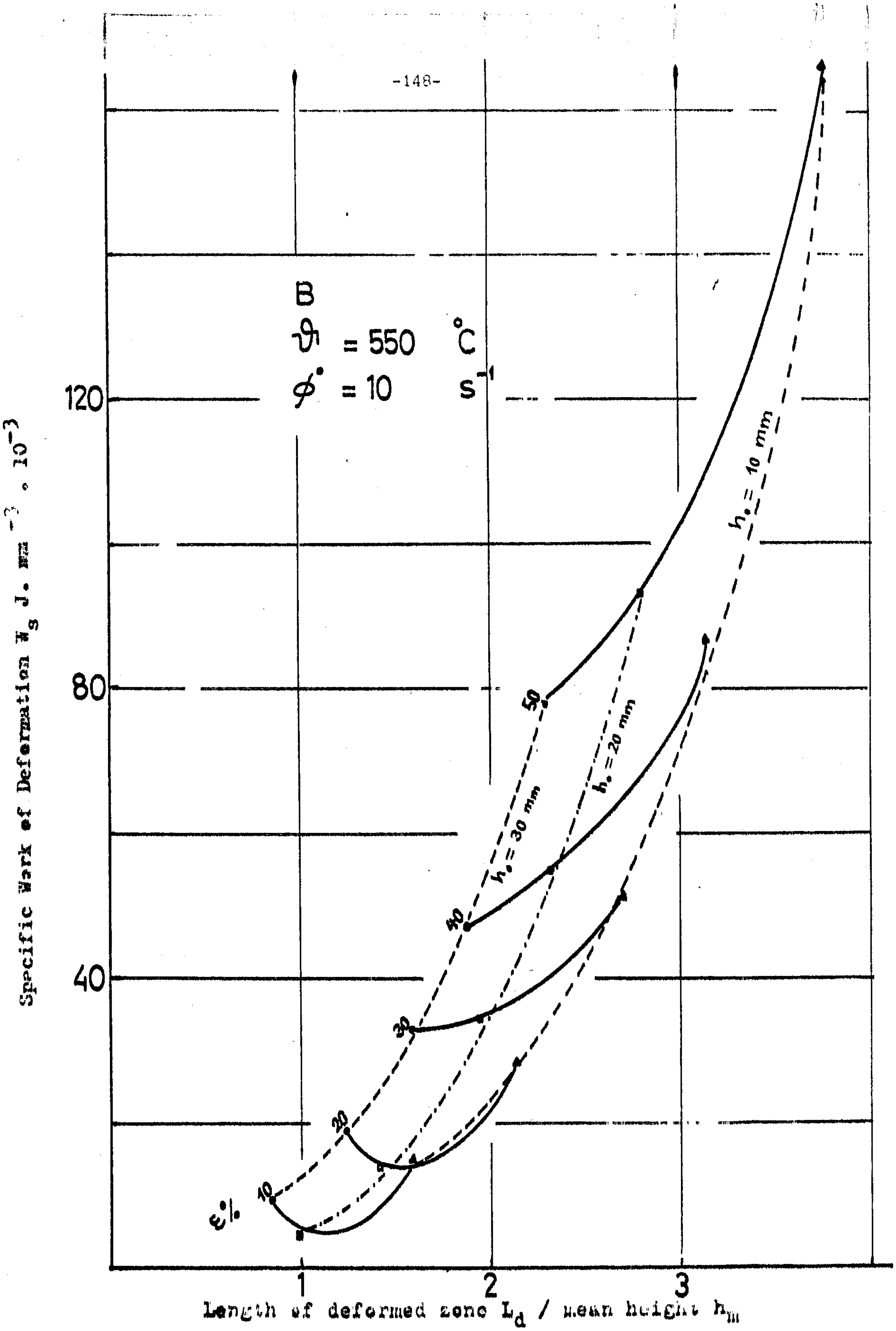


Fig. 7: Dependence of W_s on L_d/h_m for different amounts of deformation ε and initial heights of rolled specimens