MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

MECHANICAL METHOD TO DETERMINE RESIDUAL STRESSES IN CARBURISED STEEL

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ABSTRACT

The residual stresses that generates upon carburising and hardening are allowed to undergo a relaxation process, and produce a curveture in 080M15 steel bars. The degree of curveture is found to vary depending upon the carbon distribution. The fibre stress necessary to reduce the deflection to zero is evaluated and related to the surface residual stresses. The residual stresses incarburised & hardened 080M15 steel is fund compressive when decarburisation is not allowed to take place, and tensile upon the occurance of decarburisation. Carburising conditions are veried to produce different carbon profiles, that influence the residual stress pottern. The highest compressive residual stresses of 661 MN/m^2 resulted from boost-diffuse carburising, in which the carbon content of 0.8% is maintained constant to a depth of 0.3mm. Compressive residual stresses are lowered upon the occurance of retained austenite and even further when carbides are also formed.

INTRODUCTION

Steel components are carburised and hardened in order to improve mechannical performance. One of the property requirement of carburised and hardened components is compressive residual stresses.
Fatigue strength characteristics are improved by compressive residual stresses but adversly influenced by tensile residual stresses. Carburising process if controlled properlly will generate the desirable residual stress distribution - compressive in the case & tensile in the core - . However practically it is not easy to control the carburising potential. Fall of the carburising potential (below the

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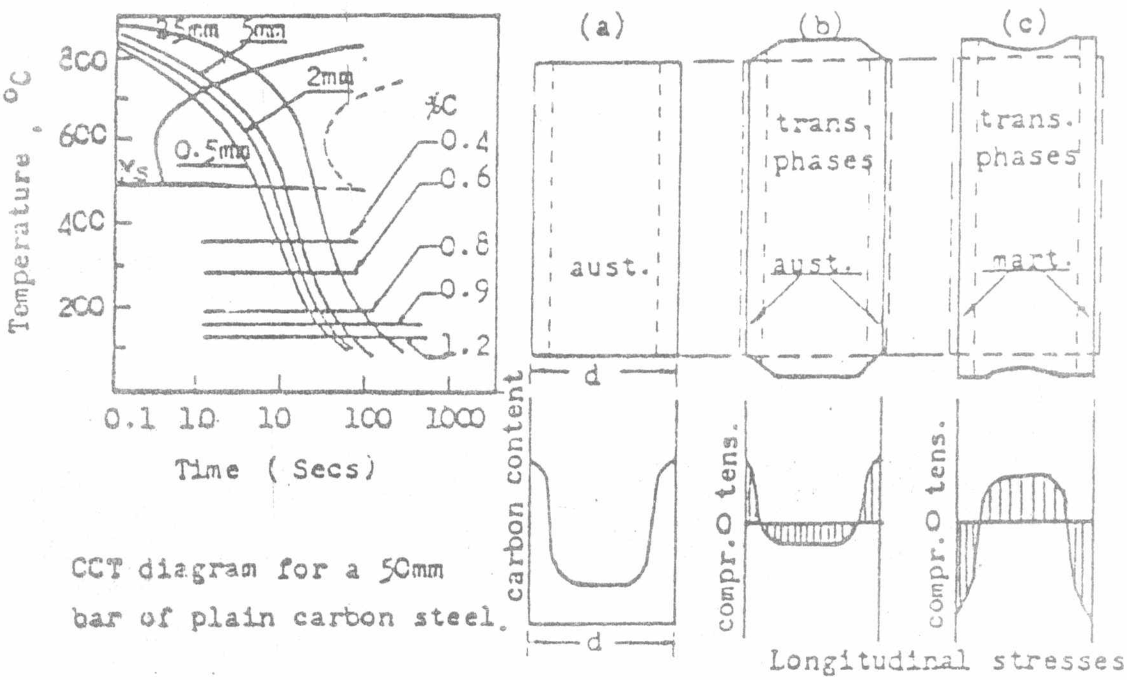
operating level) lead to surface decarburisation. This adversly affect the compressive residual stresses. Moreover if surface decarburisation is severe, tensile residual stresses are generated in the surface layer [1].
On the other hand if the carburising potential raise above the specified level carbides and/or relained austenite formation in the case will [2,3] lead to a reduced compressive residual stresses because off incomplete expansion upon transformation. The development of compressive residual stresses is one of the objectives of carburising and hardening, therefore a knowledge of the level and nature of residual stresses is quite helpful in judging the carburising and hardening practices.
On the other hand tensile residual stresses accompanies surface decarburisation and immidiate knowledge & awarness in the event of decarburisation would prove quite objective.
Residual stress measurement by X-ray techniques is the most accurate, but it is restricted by various limitations. Their measurement by a mechanical method could not replace the X-ray technique, but may be applied with far less restrictions and at the same time provides reasonable results that serves particular purposes.
The work reported here, review the generation of residual stresses, and suggest a model to estimate these stresses.

GENERATION OF RESIDUAL STRESSES.

Thermal contraction upon cooling give rise to the formation of residual stresses, these are superimposed with the stresses due to expansion during transformation.
The transformation of austenite, ferrite, pearlite, bainite and/or martensite is accompanied by volume change of the steel. On quenching steel different parts will undergo the transformation at different temperatures[4] .
The time lag of transformation with in carburised steel give rise to internal compatability stresses, which will consequently be accompanied by the generation of residual stresses [5] .
The generation of residual stresses can be fllowed by using the continous cooling transformation curve, shown in Fig.1 that of low carbon steel with carbon gradient through the case.
It can be seen that the core with its low carbon content will transform before the beginning of transformation in the high carbon case. Therefore the core will expand in the radial and circumferential as well as in the axial direction. While the case has no tendency to change its volume at that time, the austenite which comprises the case is sufficiently plastic at that temperature, that it will undergo sizeable plastic deformation to maintain compatability with the (now larger) core. It will, however, afford some resistance to the forces causing deformation, so that axial tension will be created in the case, with the corresponding compressive stresses being generated in the core. The resulting stress distribution is shown in panel b of Fig.1



CCT diagram for a 50mm bar of plain carbon steel.

Fig.1. Schematic illustration of the development of residual stresses on quenching a case-carburised plain carbon steel (0.15%C) bar, 50mm dia.

On further cooling, the austenitic surface undergoes its plastic deformation and would tend to exhibit the attendant increase in volume on transformation. However the presence of the (now) cool rigid core prevents the surface, or case, from undergoing its full free-body expansion. Consequently the case actually has smaller dimensions than it could otherwise have, and thus it will be under a state of compressive stresses, and the final stress distribution in the axial direction is shown again in Figure 1, panel c.

EXPERIMENTAL TECHNIQUES.

Plain carbon steel 080M15 having, the chemical composition shown in table 1 was used:

Table 1

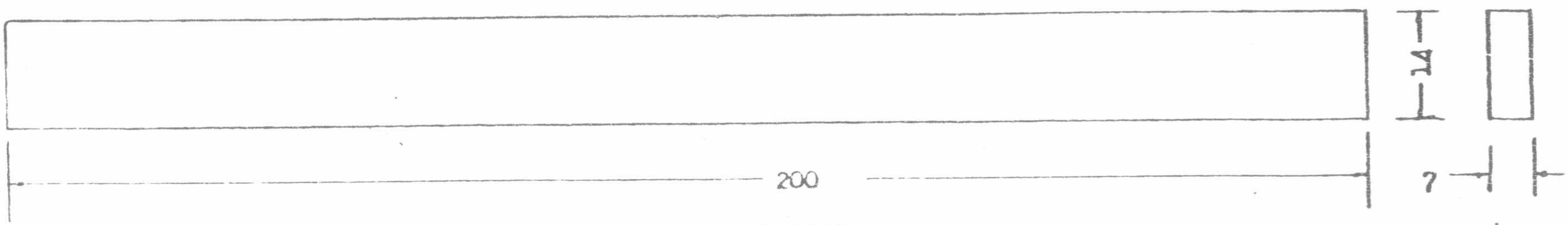
C	Si	Mn
0.15	0.12	0.64

Flat bars were shaped, ground & normalised to ensure their freedom from intenal stresses due to machinging.
Copper plating was applied in order that carburising may occure on one side only, skimming bar of the same steel were subjected to the same treatments as the flat bars, in order to determine the carbon distribution. Geometry & dimensions of the bars are shown in Fig.2
Carburising details are given in table 2, Hardening from carburising temperature in a sealed quenched furnace was adopted while no tempering treatment was applied since even 200 ^{o}C temper removes 35% of the residual stresses.

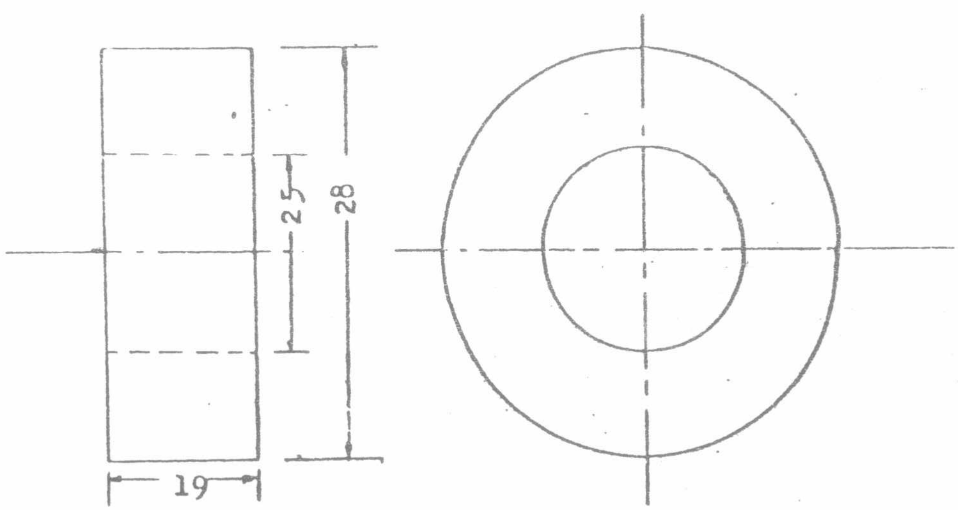
BASIS OF CALCULATIONS

Considering a flat bar, the developed residual stress distribution is symetrical about the central axis of the bar, such that the effect of stresses on one side of the axis is balanced and counteracted by the effect of those on the other side of the axis Fig. 1
Consequently if the flat bar at half thickness is carburised on one side only, the generated residual stresses will exert their effect and produce a curveture. The resulting curveture is characterised by the maximum deflection at mid-tength of the bar.
The generated residual stress undergoes gradual modification during the formation of the curveture, in other words the compressive residual stresses in the carburised surface decreases significantly, leading to the resdistribution of residual stresses such that in the final state of the bar the bending moments due to these stresses are balanced.
The deflection produced in the flat bars as a result of carburising and hardening treatment was utilised for estimating a mean value of the residual stresses. An

Fig.2 Geometry and dimensios (mm)



Residual stress measurement piece.



Skimming bar sample.

Table:2

Thermal and thermochemical (carburising) treatments in conventional gas carburising atmosphere at 925°C

Group	Technique	Time/minutes	% Carbon Potential	Nature of carbon profile
H	-	45	Neutral to the steel	-
G_1	Boost diffuse	300 60	1.2 0.8	Flat plateau near surface
G_2	Boost diffuse	255 24	1.2 0.35	Decarbur-ised
G_3	Single stage	300	0.88	Steep
G_5	Single stage	480	1.2	Over Carburised

6

assumption is being made that the majority of residual stresses have relaxed to produce the deflection. Deflection has occurred due to a negative bending moment M_r Therefore if the beam is to stay in straight condition an equivalent bending moment with opposite sign is required, M. In reference to Fig.3 residual stresses were assumed uniform, compressive in the case, tensile in the core, (only Longitudinal stresses are considered).

$$\sigma_s \cdot d = (t-d)\,\sigma_c$$

$$\sigma_c = \sigma_s \frac{d}{t-d}$$

where σ_C is the core stress

σ_S is surface stress

d is the case depth

t is the thickness

assuming W is the width

It follows that the bending moment due to residual stresses M_r

$$M_r = \int_0^d \sigma_s W x\, dx - \int_d^t \sigma_s \frac{d}{t-d} W x\, dx$$

$$= \sigma_s W \left[\frac{d^2}{2} - \frac{d(t+d)}{2}\right]$$

$$M_r = -\sigma_s W \frac{dt}{2} \qquad \text{(I)}$$

An external bending moment which would bring the deflection to zero should have the same magnitude but an opposite sign. This externally applied bending moment due to the three-point loading will be associated with a fibre stress σ

$$M = \frac{\sigma I}{Y} = \frac{\sigma\, W t^3/12}{t/2}$$

$$M = \frac{\sigma W t^2}{6} \qquad \text{(II)}$$

equating (I) and (II) it follows that:

$$\sigma_s \, w \frac{dt}{2} = \frac{\sigma w t^2}{6}$$

$$\sigma_s = \frac{\sigma t}{3d}$$

where σ is the applied fibre stress

RESULTS.

Carbon profiles determined by chemical analysis using Strohlein apparatus are shown in Fig. 4. Residual stresses with the necessary data are shown in tabel 3. An example of their calculation is shown below. It should be noted that when the bar bends on the copper plated side, deflection Δf is considered posative, vice versa if it bends on the carburised side.

Residual stress calculation was carried out using

$$\sigma_s = \frac{\sigma t}{3d}$$

$$\sigma = \frac{MY}{I}$$

$$= \frac{PS}{2} \cdot \frac{t/2}{wt^3} \cdot 12$$

$$= \frac{3PS}{2wt^2}$$

$$\sigma_s = \frac{3}{2} \frac{PS}{wt^2} \cdot \frac{t}{3d}$$

$$= \frac{PS}{2wtd}$$ (Span length S was always 180 mm)

For example G_1 $\sigma_s = \dfrac{20(180)}{2(15.9)(7)(0.88)}$

$= 661 \text{ N/mm}^2$

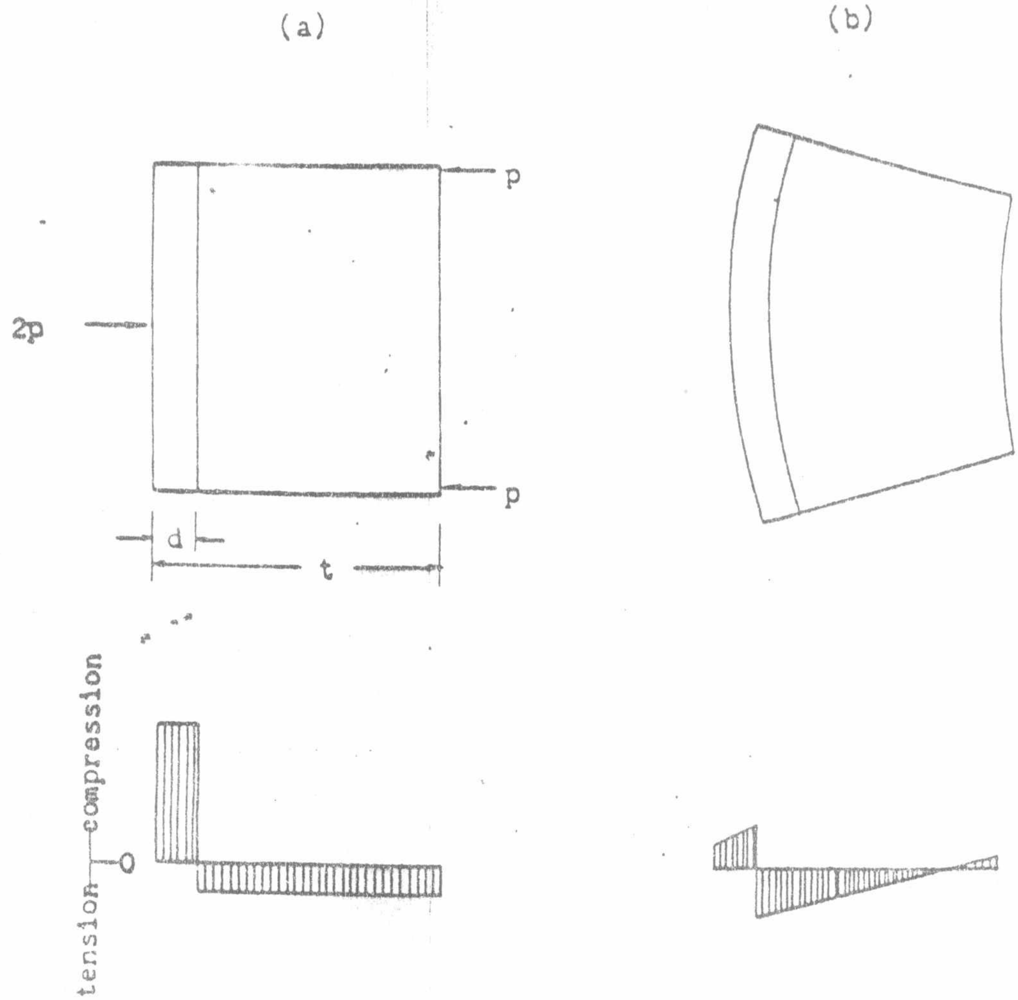


Fig. 3 Schematic illustration of residual stress and distortion; Panel (a) shows the beam in a balanced state, under the effect of both residual & applied stresses, panel (b) shows the beam distorted with the resulting stress distribution.

Table.3, Data of Residual Stresses on Carburised.
080M15

Thermo-Chemical Treatment	Deflection (Δf) mm	Effective case depth (d) mm	Dimension, mm thickness (t)	width (w)	Load at zero deflection (p) N	Surface Carbon %	Surface Residual stress N mm^{-2}
G1	-1.8	0.88	7.0	15.9	720	0.78	-661
G2	+0.2	0.79	6.9	15.9	100	0.48	+103
G3	-1.5	1.0	7.0	14.2	560	0.82	-507
G5	-1.8	1.6	7.0	15.8	600	1.2	-306

Supplement to Fig 4.

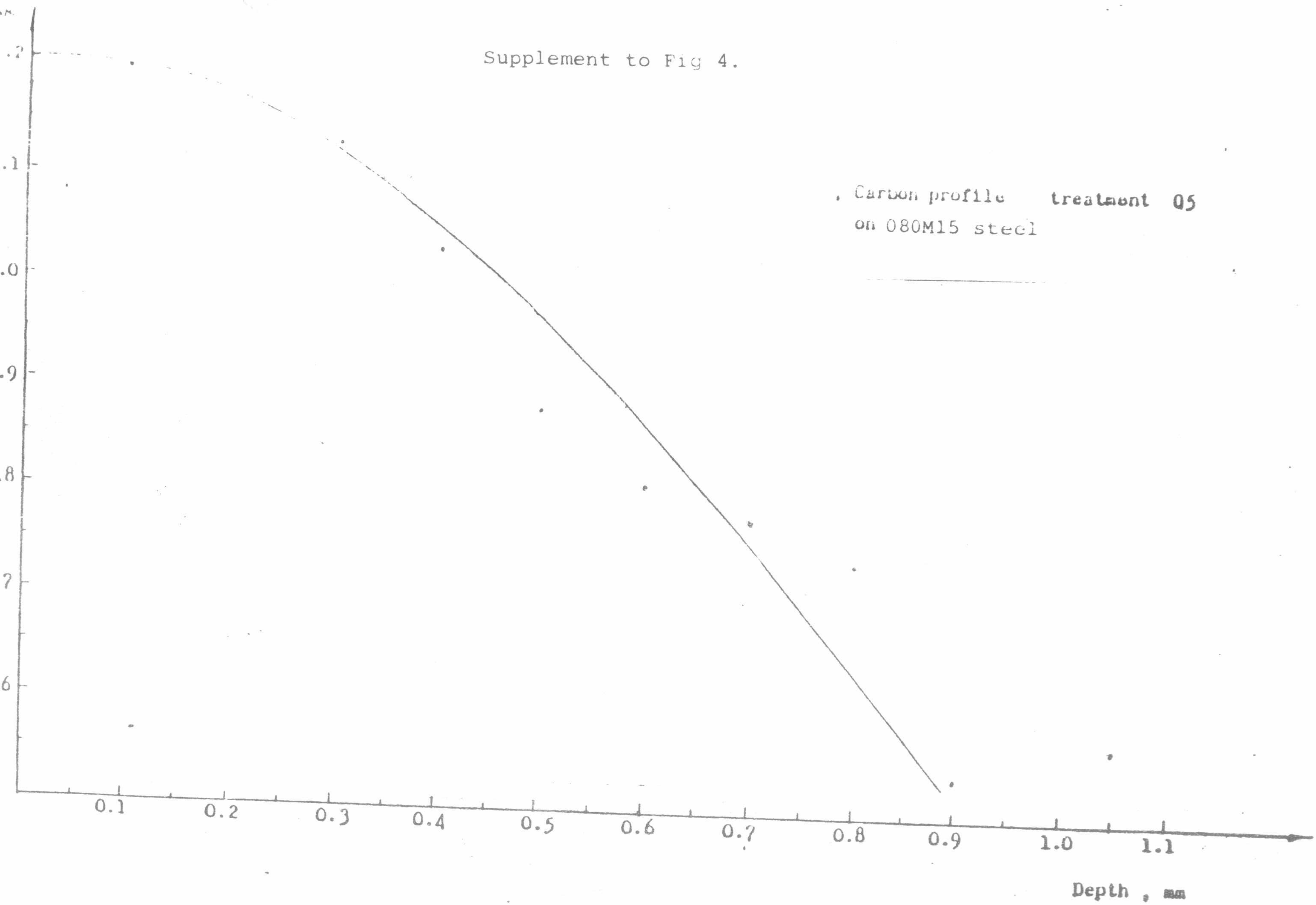
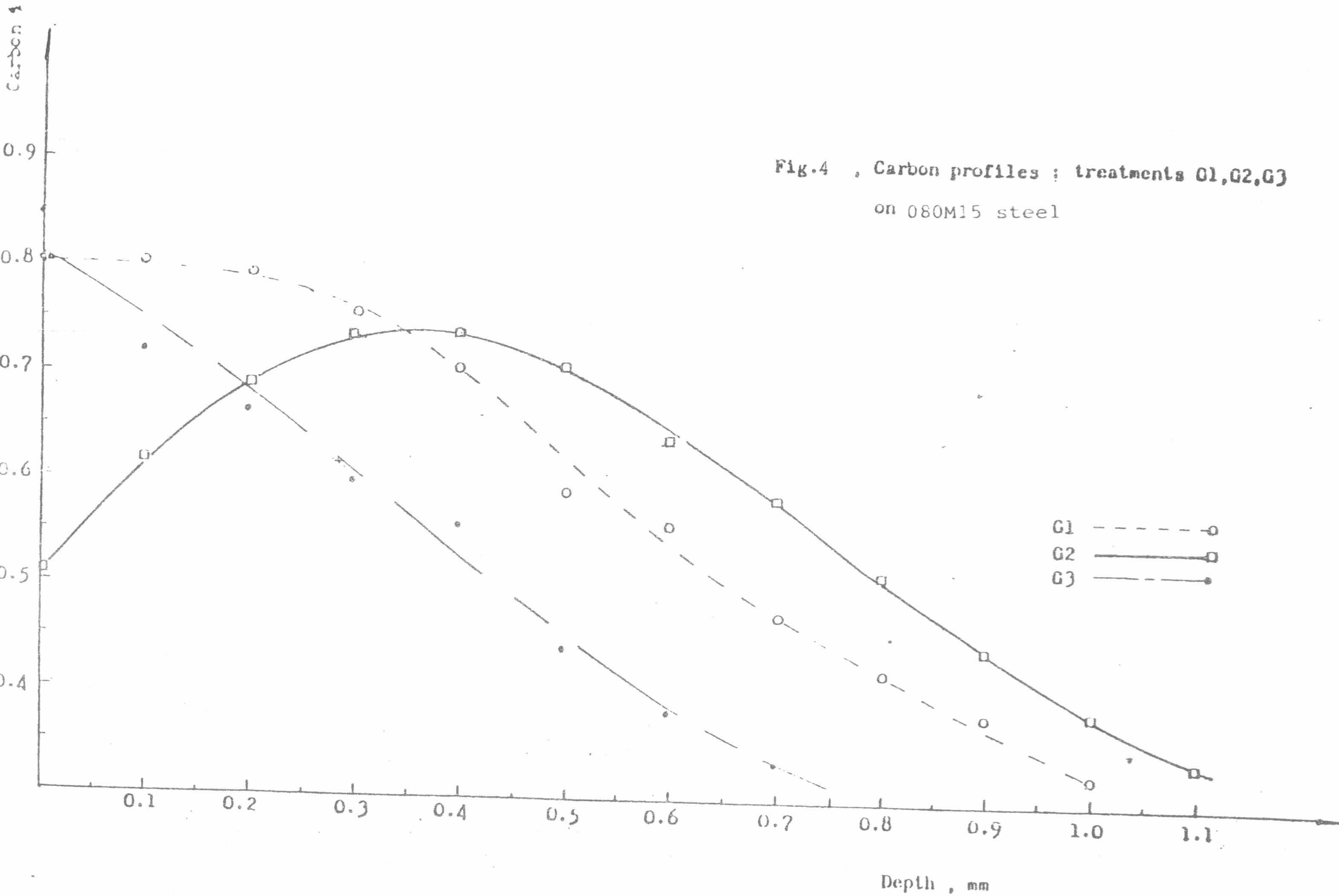


Fig.4 , Carbon profiles : treatments G1,G2,G3 on 080M15 steel



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DISCUSSION

It can be seen from table 3. that surface residual stresses determined, are compressive in all cares except when surface decarburisation is allwoed to take place.
Maximum compressive stresses have resulted from boost-diffuse carburising (G1), the care microstructure is found martensitic with limited (4%) amount of retained austenite.
Single stage carburising (G3), resulted in a slight loss of compressive stresses, case microstructure contained relatively higher amount of retained austenite, this is expectef to lower the compressive stresses. Their value determined as 507 Nmm^2 which is 23% lower than the 661 Nmm^2 due to (G1).
Overcarburising to a surface carbon content of 1.2% resulted in the formation of retained austenite and carbides, were revealed upon microstructaral examination. The compressive residual stresses are found to be reduced by 54%.
Surface decarburisation (G2) has resulted in the complete loss of compressive stresses, as tensile stresses of about 100 N/mm^2 has resulted instead. Surface decarburisation is evident from the carbon profile Fig 4. Hardening without carburising produced zero deflection, i.e zero stresses.

CONCLUSION

The method produced acceptable results that corrolates with metallurgical features of known effects.

REFERENCES

1. V.S. Sagaradze and c.v. Malygina, "Influence of decarburisation on the properties of case hardened steel", Metal Science & Heat Treatment, 7, pp. 560-563, July, 1966.

2. C. Razim, "Influence of residual austenite on the strength and Properties of Case - hardened test pieces during fatiguing", Harterei - Technisce Mitteilunger, 23, pp. 1-8, April, 1968 Translation BISI 6448.

3. K. Kuo "Carbides in Chromium, molybdenum and tungsten steels", Journal of the Iron and steel Institute, 173, pp. 363-375, April, 1953.

4. A. Rose and H.P. Hougardy, "Transformation characteristics and hardenability of carburising steels", symposiom Transformation and Hardenability in steels; pp. 155-156, Feb. 27-28, 1967.

5. C. Dawes & R.J. Cooksey, "Surface treatment of Engineering components", Heat Treatment of Metals; special report 95, I.S.I, pp. 68-105.