STRESS GENERATION AND DISTRIBUTION IN REFRACTORY TUYERES

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ABSTRACT

This work covers the analysis of stress and strain distribution in a model that supplies information on the behaviour of the refractory lining provided in the line of tuyeres of a PS-converter . This method can be used for calculating the expansion joints of any desired refractory lining.

Tuyeres punching and cleaning is performed by applying the impact of an iron bar against tuyeres obstruction that may be copper, copper sulfide or slag.

The following Cases are analysed in this work : a monolithic tuyere under static conditions , a monolithic one but under impact and the actual tuyeres lining comprising several wedges under dynamic stress. The dynamic stress conditions are represented by an impacting force that is actuating during a defined time.

In both instances it may be concluded that stresses originated by the impact for cleaning the tuyeres are higher than the mechanical strength or whatever refractory now used in said tuyere zone, especially when tuyere clogging is constituted by hardened copper whose mechanical strength is 3 to 4 times that of refractories used in the tuyere lining.

The results strengthen the proposal of carrying out some permanent preventive cleaning without awaiting for a certain reduction in the pressure or flow of blowing through the tuyeres . Using shorter application for the impacting force the resulting refractory destruction is lesser than the originated through longer application of the force.

- INTRODUCTION AND PURPOSES

Nowadays the Peirce Smith converter is being used both for the processing of matte proudced by open-hearth furnaces, and for the high-copper white metal produced by Modified Teniente Converter (MTC) , the Noranda reactor or Outokumpu flash furnace. When processing white metal enriched with copper in the Ps converter in a predominant way , there occurs a life decrease in the line of tuyeres without any increase in the specific consumption of refractory materials , and this fact indicates a higher efficiency achieved despite the more frequent repairs made in said lining.

Traditional converter comprise a horizontal metallic cylinder having a refractory lining and an opening through which loading and discharge operations of the converter are performed. This cylinder includes two vertical walls forming the converter heads. Converters of the most usual size are 4 meters in diameter and about 9 to 11 meters long.

Up to some time ago the converter was operated using two succesive steps. In the first the iron was oxidised whith the formation of fayalitic slag , while the second step comprised the blowing to get copper. Owing the energy-consumption reasons there has been gradually discarded the use of open-hearth furnace requiring a very high amount of fuel oil for melting copper concentrate and for producing matte for the first step of blowing in the converter.

Refractory lining wear in the cylinder and heads thereof is primarily caused by chemical attack and thermomechanical exigencies imposed to refractories.

Such a situation does not occur in the tuyere zone , where temperature changes are present along with temperature gradient around the tuyere, caused by air entering at temperatures under those of the molten metal, and also owing to loading and unloading movenment of the converter , which compels a lining portion to cool upon staying uncovered by the molten bath.

Besides , in the tuyeres zone there arises the problem of the obstruction due to the hardening of molten products within the same , which imposes the most severe strain on refractory materials , namely tensile stresses at high temperature causing a typical wear profil of the lining in this zone, Fig. 1a.

This mechanical strain is originated through the action of tuyeres punching when a certain blowing pressure has been reached, that has been defined as critical in accordance with the experience gathered through converter operation. Usually , when this critical blowing pressure has been reached an important infiltration into the refractory together with tuyere clogging has already occured.

At the instant of impacting with the iron bar used for the cleaning operation this bar must loosen the plug formed , but owing to an anchoraging of the hardened products in the refractory, a system constituted by the copper plug (predominantly considering the second step of blowing to produce copper) anchored in the refractory has originated. The copper is subjected to mechanical stress through the iron bar impact and , as copper has a tensile strength 8 to 10 times that of the refractory, some refractory fragment comes away each time the cleaning operation of a clogged tuyere is carried out.

Figs.1b and 1c show a simplied analysis of the application of some force in the axial direction of the tuyere, and this analysis allows to visualise the physical and mechanical efect of the cleaning operation. Figs.1b and 1c refer to the case where the tuyere is constituted by four wedges, and this figures ilustrate the resolution of the force applied as it may occur when impacting an obstructed tuyere. The force-resolution shown is only a mere sketch and not result of some computation;it serves exclusively for emphasising the action of each of the force-components originated. This force-resolution shown in Figs.1b and 1c occurs in the plane perpendicular to converter axis. A compressive stress that can be transmitted through the lining, may be observed on the refractory located in the lower part of the tuyere tube.

In the case of the upper part of it the situation is completely different inasmuch as there is a force-component acting, practically, in joint direction between adjacent wedges. The compressive stress is transformed into a tensile stress for the refractory having its own mechanical strength as the only support since it is obvious that tensile stresses cannot be transmitted between mutually separated parts.

The purpose of this work is to establish and compute the stress originated in the tuyeres zone through the cleaning operation both in the case of preformed monolithic tuyeres and in the case of multielement tuyeres. It is thus desired to contribute to the definitions of technical specifications that must be satisfied by refractory materials used in the tuyere zone of the Peirce Smith copper converter, and to the selection of the format that is the most suitable for being used in this zone.

2.-PRELIMINARY CONSIDERATIONS AND PREVIOUS WORKS

The structural response of refractory lining at high temperature is accompanied by considerable thermal expansion of the system. This expansion is restricted by the shell or by others refractory layers, thus originating high compressive stress in the materials of the refractory lining. Besides a large thermal gradient through lining thickness may accompany these stresses and produce some critical state that may include lining cracking or spalling as well as failure at brick -interface joints. In general this problem is more severe during the transient heat-up , when the stress relaxation-level due to creep caused by refractory temperature is below the level existing in the stationary state.

The finite-element analysis used herein allows prediction of the stress and strain in accordance with refractory-lining temperature during the cleaning operation of this lining.

A former work (1) has analysed the effect of the expansion jointt on lining-brick cracking and spalling as well as the failure of such joints in the brick-(mortar)-expansion-joint system, especially for the operating conditions of the converter.

Considering the usual practice of dimensioning the expansion joints it has been found that it is indispensable to mantain the capacity of movement and stress-absorption on converter heads. The necesity of insuring lining-impermeability at 6oo degrees celsius obliges the use of expansion joints of at least 1/8 inch per foot of lining length.

The lesser the strain under load in the warm state and the longer the time required for refractory relaxation , the higher is the precision required for dimensioning the expansion joints. This aseveration leads to the establishment of a scale that may start with with low alumina clay refractories ,continue wih bauxite and basic materials of conventional firing , reach materials containing at least 90% alumina and highly-fired direct bond basic materials , and end with electrofused materials having very low impurities and high moduli of elasticity.

Tomsu and Lanco (2) have computed the lining stress-state of a 500 ton torpedo car whose lining comprised 3 layers of diverse refractory materials, namely : a working or wear layer, a safety layer and an insulating layer.

In the model used by these authors the phenomenon of stress relaxation while strain and temperature remained constant in the system was emphasised. According to the results gathered by these authors the employement of mortar plays a very important role in the elimination of stresses originated through lining expansion when mortar is not being used the stress acting on the metallic shell are about 33% higher than when using mortar. These researchers do not discuss the tensile-stress transmission problem that necesarily arises during the thermal cyclic operation of the torpedo car.

Hasselmann (3) partially discusses the role played by the relaxation phenomena in peak tensions originated through a state of dynamic stress caused by temperature cycles which, obviously , depend on the operating conditions of the furnace.

Schacht (4) has analysed the stress state of a teeming ladle under (transient) preheating conditions and under operating conditions using experimental measurements performed during the operation of the ladle. Schacht has separately analysed the metallic shell and the refractory lining comprising three layers of diverse refractories. He has especially assesed the non-linear behaviour of the lining , that is to say the phenomenon of relaxation and slow creep of refractory. This author mentions in his work the use of non-linear interface elements providing a rigid-sliding boundary for compressive loads. This study is showing difficulties represented by the confrontation between computed stresses and those mechanical properties of the refractory with which these computed stresses are to be compared.

Upon the termination of this work , by the end of 1984 Chen and Buyukostturk´s excellent work (5) has appeared, providing a simultaneous modelling of mechanical stresses present and refractory-lining corrosion phenomena , and getting the design and analysis equations of refractory lining.

No prior data were found as concerns works relating to the problems of impacts applied to refractories during their operation.

3.-DESCRIPTION OF MODELS

Refractory linings now beeing used in converter walls consist of wedge-shaped parts. Between the wedges it is some times usual to put mortar, and on the other hand expansion joints are provided with a 18-inch to 27-inch spacing. Temperature increase in the work room of furnaces produces in the lining a temperature gradient that causes a differencial expansion precisely in keeping with this gradient , which fact produces the partial closure of expansion joints and the mutual contacting between adjacent wedges separated prior to heating . The lining design cannot transmit tebsile stress but is able to transmit compressive stress.

Another alternative design is constitutted by the monolithic lining which , at variance with the above-mentioned multielement lining, behaves as a whole without any separations and is capable of transmitting all sorts of stresses independently of their direction.

In order to establish in this study the stresses generated through the punching operation to clean the tuyere, the following model are considered :

i) a monolithic tuyere subjected to a static load and then to a dynamic load caused by impact.

ii) a tuyere constituted by several elements and subjected to dynamic load caused by impact.

In both instances the finite-element method is employed for computing the stresses in the diverese zones of the lining around the tuyere. The following boundary conditions are considered for this computation :

Case i) : With a view to simplifying computations it is considered that, since the force is applied on the tuyere-axis direction and since the impact zone will be a small compared with the converter length , it may be accepted that the affected zone will be a small portion of the total zone that includes the tuyere and the copper plug obstructing the same , Fig. 2.

In Fig. 2 the length L is the distance run by a transverse wave for a duration ... of the impact. Besides, taking into account that impact duration may be estimated as being the time required fby the wave for traversing the overall length of the impacting iron bar, as follows :

where : Cb = sound speed in steel,
Cr = sound speed in the refractory material,
lb = iron bar length

The difficulty for ascertaining the load-variation function is solved assuming that the variation of the force applied during the impact time-interval is constant, with allows to asses the same taking into account the amount of movement supplied. The relationship defining this situation is as follows :

and hence

where :

m = iron bar mass,
v = exact speed prior to the impact,
Υ = impact duration.

Once this force is known it is feasible to carry out the analysis for the dynamic case and then for the static case in this way is possible to express stress magnitude as a function of the speed with which the cleaning operation is being performed in the tuyere .

Using the symmetrical characteristics of the problem that is being considered an axially symmetric analysis is undertaking employing finite elements.

Case ii) : Boundary conditions imposed by this second model lead to another way of dealing with the problem, basically owing to the mutual separation of parts and the existence of expansion joints.

The temperaure gradiente existing in the lining and causing a partial contact between adjacent refractory parts, defines that only at the limits of the parts where this contact has occurred it is possible to think about compressive-stress transmission at the time of impact. On the contrary , when tensile stress are generated the transmission of compressive stress will not occur but instead adjacent parts will propend to become separated.

Besides , the dimensions of the converter are considered , whose length is much larger than lining thickness, and though the applied load is concentrated at one point it is possible to analyse with good aproximation a slice only of a cross-section of unitary thickness , which allows dealing with the problem through an analysis of plane deformations.

Wedges separation is considered by using two non-linear bar elements , Fig. 3 , which permit stress transmission when some compression is existing between adjacent wedges (active bar) while in the instance of some separation caused by tension they will not interact (passive bar) . In this fashion the influence of expansion joints existing in the lining may be modeled.

The active bar is exhibiting the same behaviour under tension and under compression , with a high modulus of elasticity so as to behave rigidly , undergo no deformattion, and transmit stress only.

The passive bar is admiting tensile sress only , that is to say when two adjacent refractory parts are being compressed ; otherwise the bar is failing and stress is not transmitted.

Upon the formulations of these considerations a tuyere is modelled with various elementes in accordance with the diagram shown in Fig. 4. The force applied and the duration of the impact are the same as those used in the first model.

Fig.4 shows the tuyere passing through five bricks , and between the wedges there may be seen the bar elements that simulated the expansion joint and the copper plug that is to be impacted by force F.

4.-RESULTS AND DISCUSSION

Figs. 5 and 6 show the shearing stresses and main stresses for the case of monolithic tuyere subjected to a static load uniformely applied to the plug that is obstructing the tuyere.

In this case the values reached by shearing stresses as well as main stresses largely exceed the strength of the refractory material. Tensile stress is almost 13oo kg/cm2 in the upper zone of the plug. If this value is compared with the flexural stress if highly-fired basic brick normally amounting to 20 kg/cm2 it may be seen that is impossible for a portion of the brick to avoid being destroyed as a result of a static stress as the one computed.

In addition it has been found that regarding the more distant zones , already at a distance of about 10 centimeers from the tuyere axis the tensions are rapidly decreasing and the existing stresses are almost irrelevant and cannot cause any refractory damage.

Owing to the high value of the stresses generated in this case , it is thinkable that the refractory will fail before theses stresses are reached , and that then refractory-fragmentes will loosen along with the copper plug.

With a view to determining exactly the instantat which the failure occurs and to knowing the stresses existing at this instant -- that is to say, when the loosening of the copper plug is produced -- , a dynamic analysis was carried out endeavouring as much as possible to aproximate the model to the practical existing situation during the cleaning operation.

For an impact lasting .ooo35 seconds when carrying out the dynamic analysis at the initial instant of plug loosening, Fig. 7

shows the plotting of radial stress at the chronological instant T = .00007 seconds as a function of the position.

It may be observed that stress values are obviously higher in the impact zone and that rapidly decrease while "z" and "r" are increasing.

In Fig. 8 stress values in the "z" direction are plotted for differents time intervals as a function of "z" and for a value of "r" equal to 4,45 centimeters corresponding to the copper-refractory contact zone. In all the curves the peak values is appearing for z = 15 cms. aproximately .

In like fashion Fig. 9 shows the shearing-stress curves for the contact zone.

At last the results corresponding to the stresses generated by some dynamic load caused by the iron bar impact are supplied below for the case of the tuyere constituted by several elements . According to these results and to strength values of copper and refractories it may be deduced that the copper starts loosening at instant T =.000021 seconds.

Table 1 supplies the values of the sresses developed for this chronological instant in each finite element in accordance with the mesh shown in Fig. 4.

In the first place may be observed that sresses are close to zero in the case of the elements 28 to 34 , because adjacent bricks propend to become separated and there is almost no stress transmission between them ; in other words the majority of passive bars is in a compressive state. No stress is produced as regards the next element (35 to 55), which fact confirms the model in the sense that no stress transmission is to occur when the elements separate.

For the lower brick (elements 1 to 6) generated stresses are mainly compressive stresses, which occurs in practice owing to the direction of the impacting force , though its magnitudes are relatively reduced.

On the other hand , if we considere the stresses generated in the two bricks mutually connected through the copper plug (elements 7 to 27) we may observe that the greatest stresses are produced in the impact zone and their magnitudes are sufficient to open the tuyere conduit in accordance with copper and refractory strength. Even more , there should occur the loosening of the wedge formed by elements 23 to 27 and elements 18, which fact has been verified in practice.

As we are moving farther away from the contact zone we may see that stresses become irrelevant , so that no damage should be produced.

5.-CONCLUSIONS

The magnitudes and distribution of the stresses generated in the cases that have been studied exhibit considerable differences among them when carrying out a static analysis and a dynamic one. Thus for the static case the highest main stress is on the order of 13oo kg/cm2 in comparison with 40 kg/cm2 produced in the dynamic analysis at the loosening instant of the plug. However , in both instances the generated sresses appear in the copper-refractory contact zones , and they substantially decrease in locations more and more distant from the hot zone.

Both analysis permit to conclude that if impact time is reduced while applied force is simultaneously increased , then it is possible to get a reduction in the size of the damaged zone and to thus remove the cumulated hardened copper without destroying the refractory.

As regards tuyere type the following observations may be formulated. In the case of the monolithic tuyere there is a compact mass measuring about 6ox140 square centimeters and which causes stress transmission through the whole section when subjected to an impacting force, the most impostant stresses being produced in the copper plug zones and amounting to about 280 kg/cm2.

On the other hand , in the tuxere comprising wedges and exhibiting distinction between one element and the other , stresses are assimilated by only bricks surrounding the plug, in an area measuring about 16x46 square centimeters and then stresses are reaching values on the order of 550 kg/cm2.

Though peak tensile stresses that the refractory can withstand are exceeded in both instances , the monolithic tuyere allows a partial distribution of the load to farther-away zones so that lower stresses are then generated in the critical zone . Hence this sort of tuyere represents a more favourable alternative design , on condition that the mechanical exigency imposed by the cleaning operation predominate over the thermomechanical exigencies ordinarily present during converter operation.

The results confirm the fact that the cleaning operation is producing damage , especially during the second step of blowing , inasmuch as fayalitic slags loosen easily becauses of their low mechanical properties . In this case the pricking with the iron bar can be undertaken without any problems in the converter at a temperature below the one at which the converter becomes clogged with copper.

The monolithical lining would be advantageous only if it can withstands the chemical and thermochemical exigencies as well as the brick lining actually does , simultaneously with lesser time lining methods .

6.-ACKNOWLEDGEMENTS

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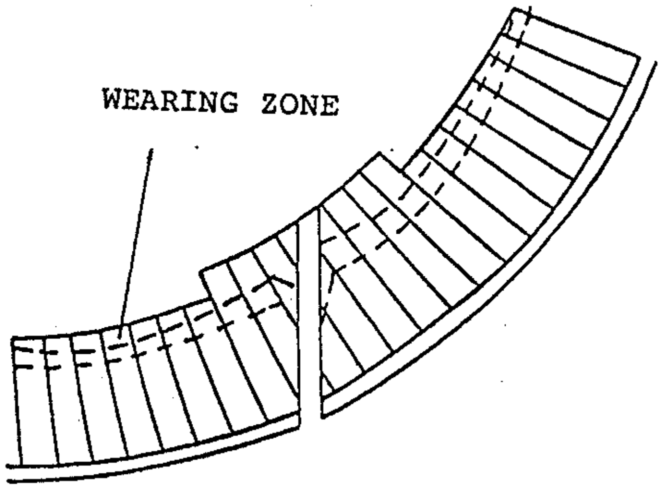
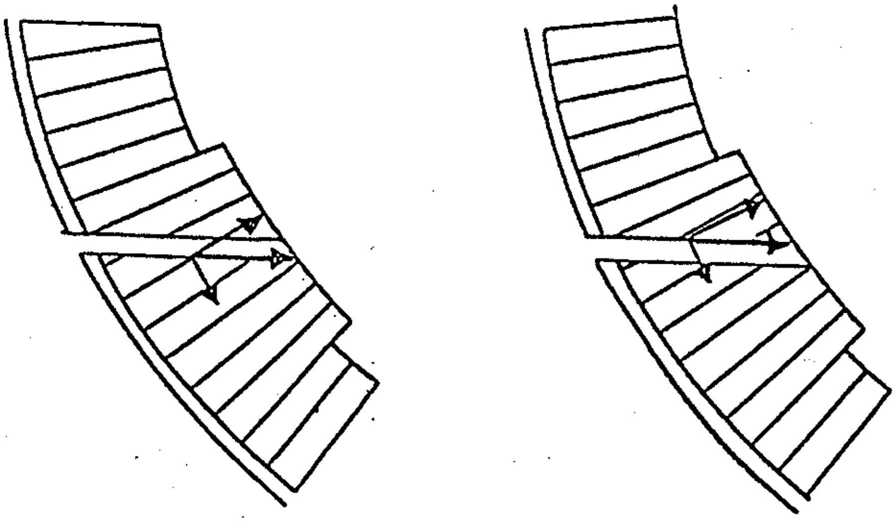
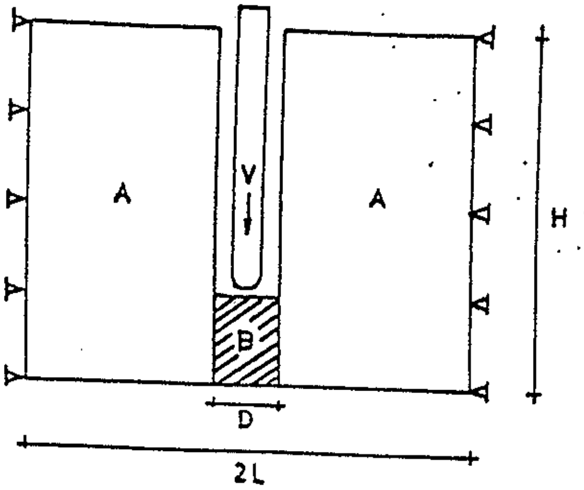


Fig. 1a Deterioration and wear-profile of the refractory lining provided in a Peirce-Smith converter.



Figs. 1b and 1c Resolution of a force applied to the lower part and to the upper part, respectively, of the tuyere.



A : refractory material

B : hardened copper

V : speed of the impact

2L : distance considered for the analysis

H : mean thickness of the lining.

Fig. 2 Illustration of the monolithic model of the tuyere obstructed with hardened copper.

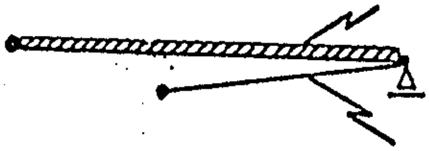


Fig. 3 Diagram of active bar and passive bar.

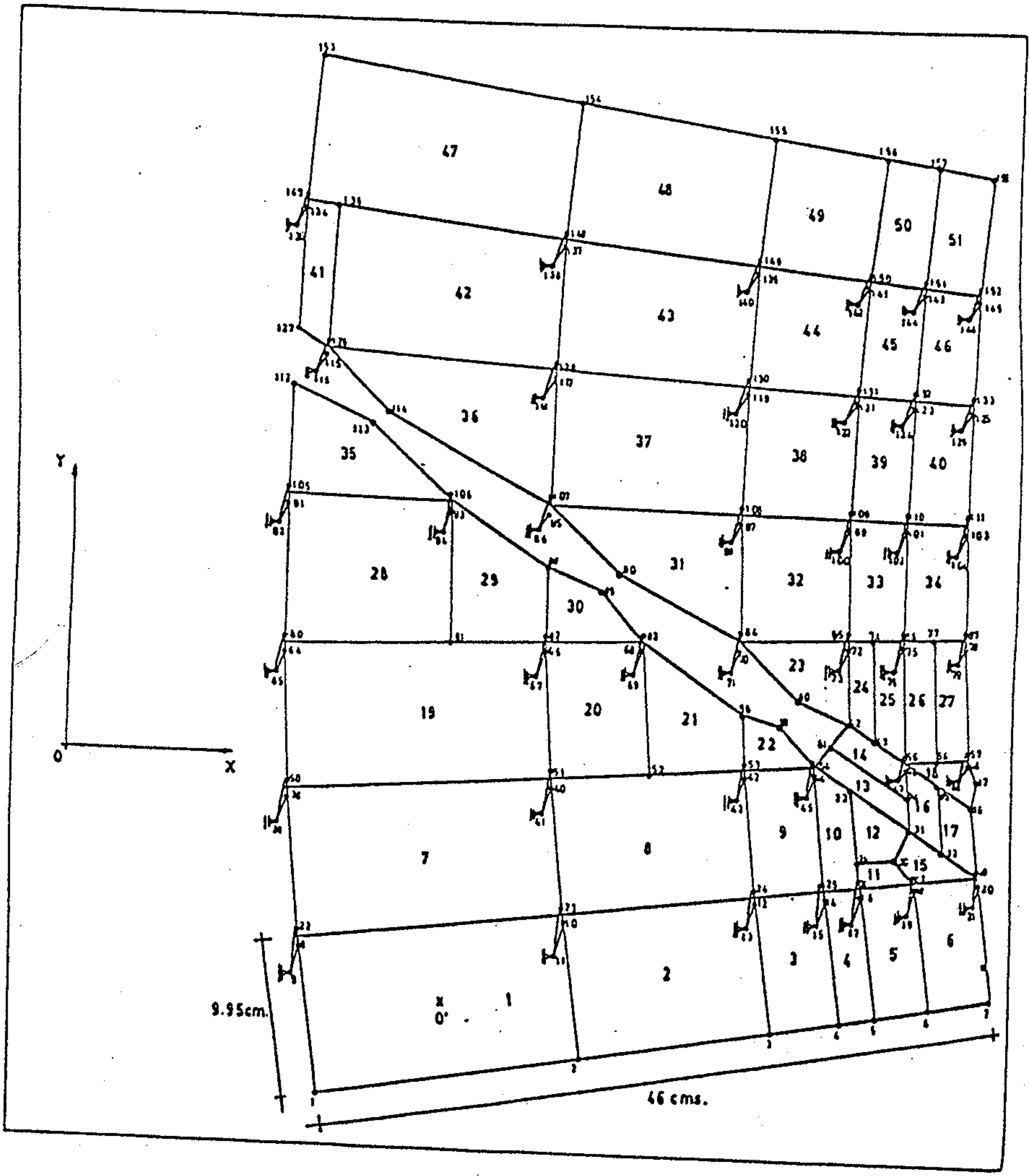


Fig. 4 Topology of the mesh used for studying a tuyere, constituted by several elements, through an analysis of plane deformations.

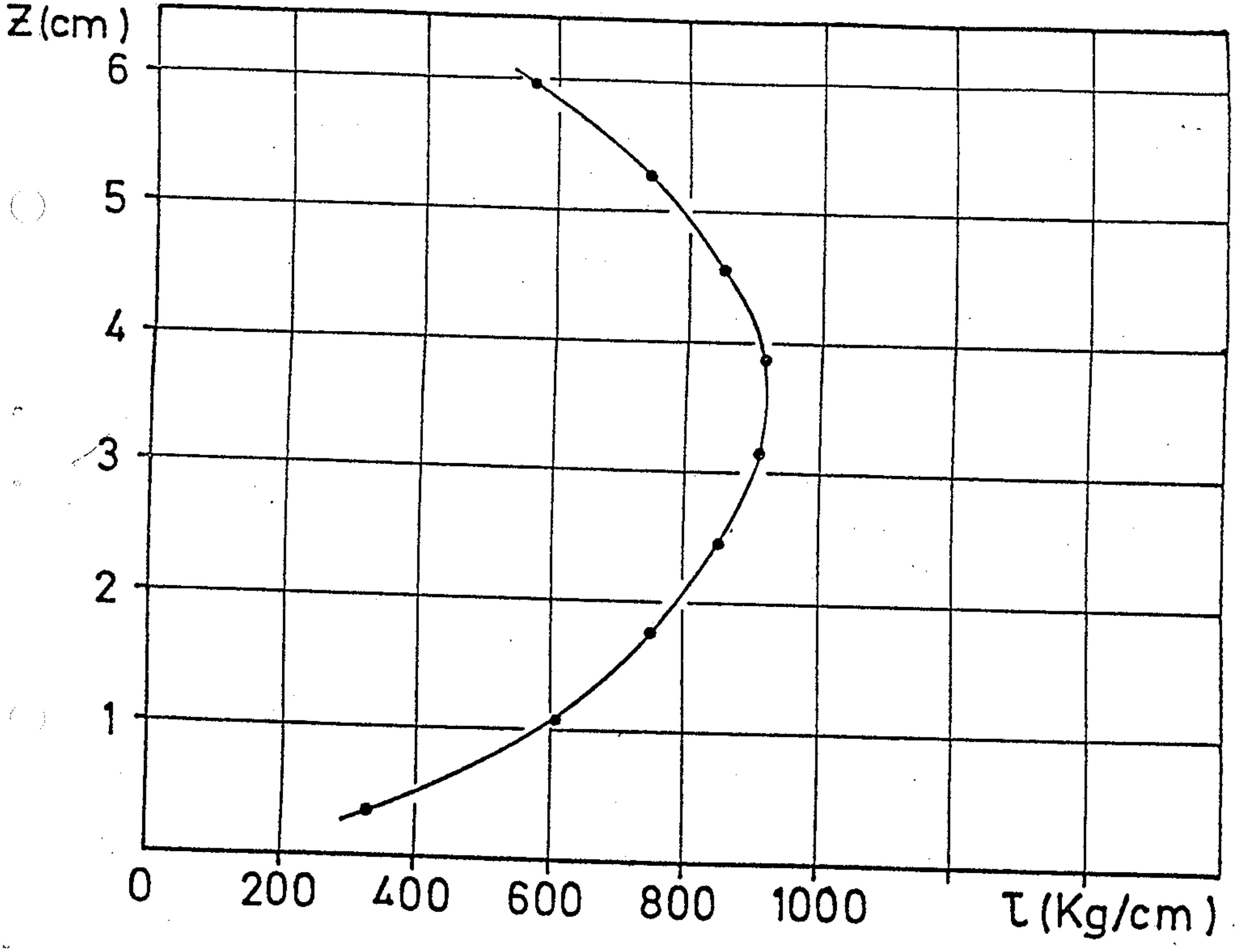


Fig. 5 Distribution of the shearing stress in the copper-refractor boundary zone.

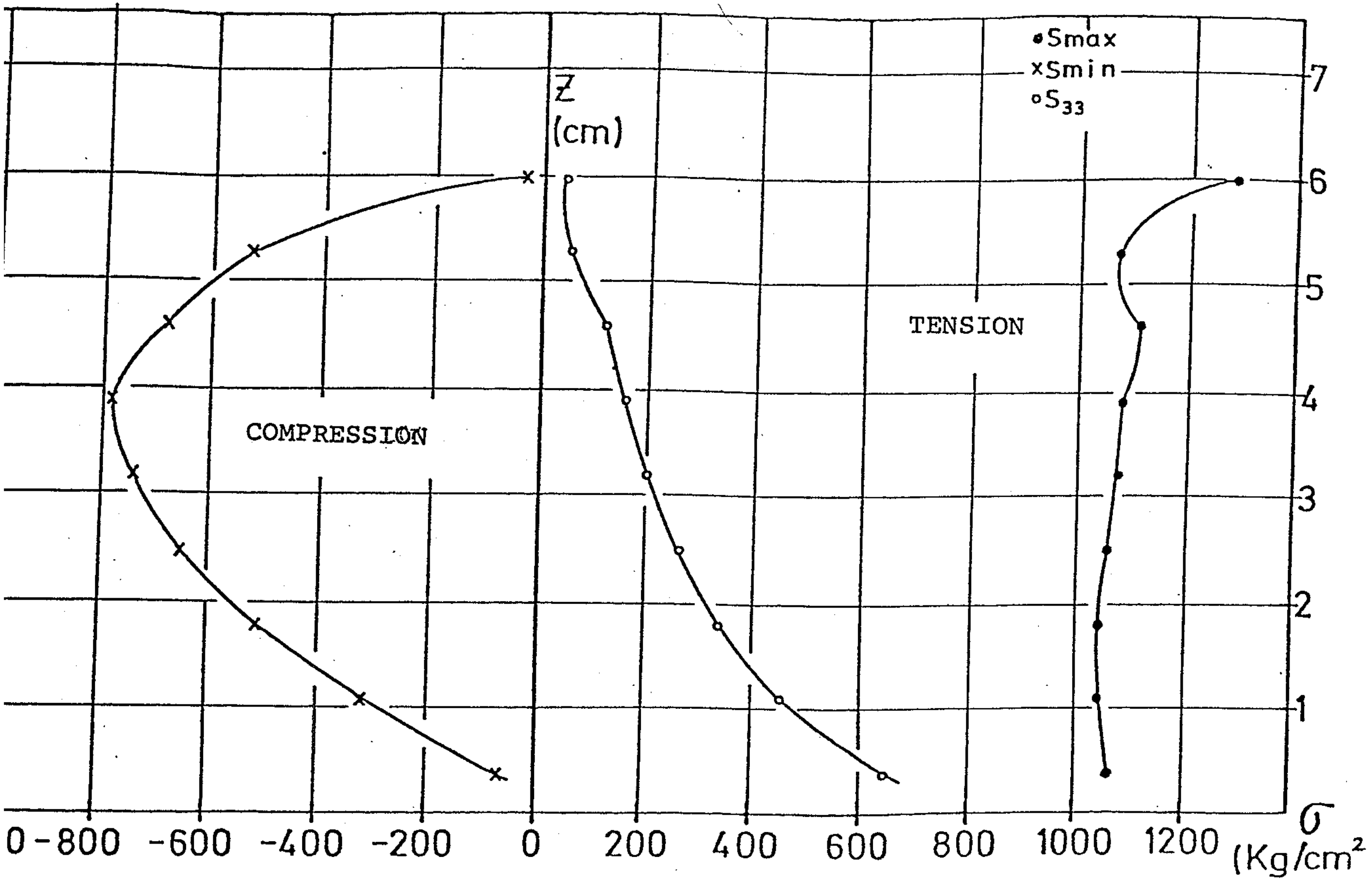


Fig. 6 Distribution of the main stresses in the copper-refractory boundary zone.

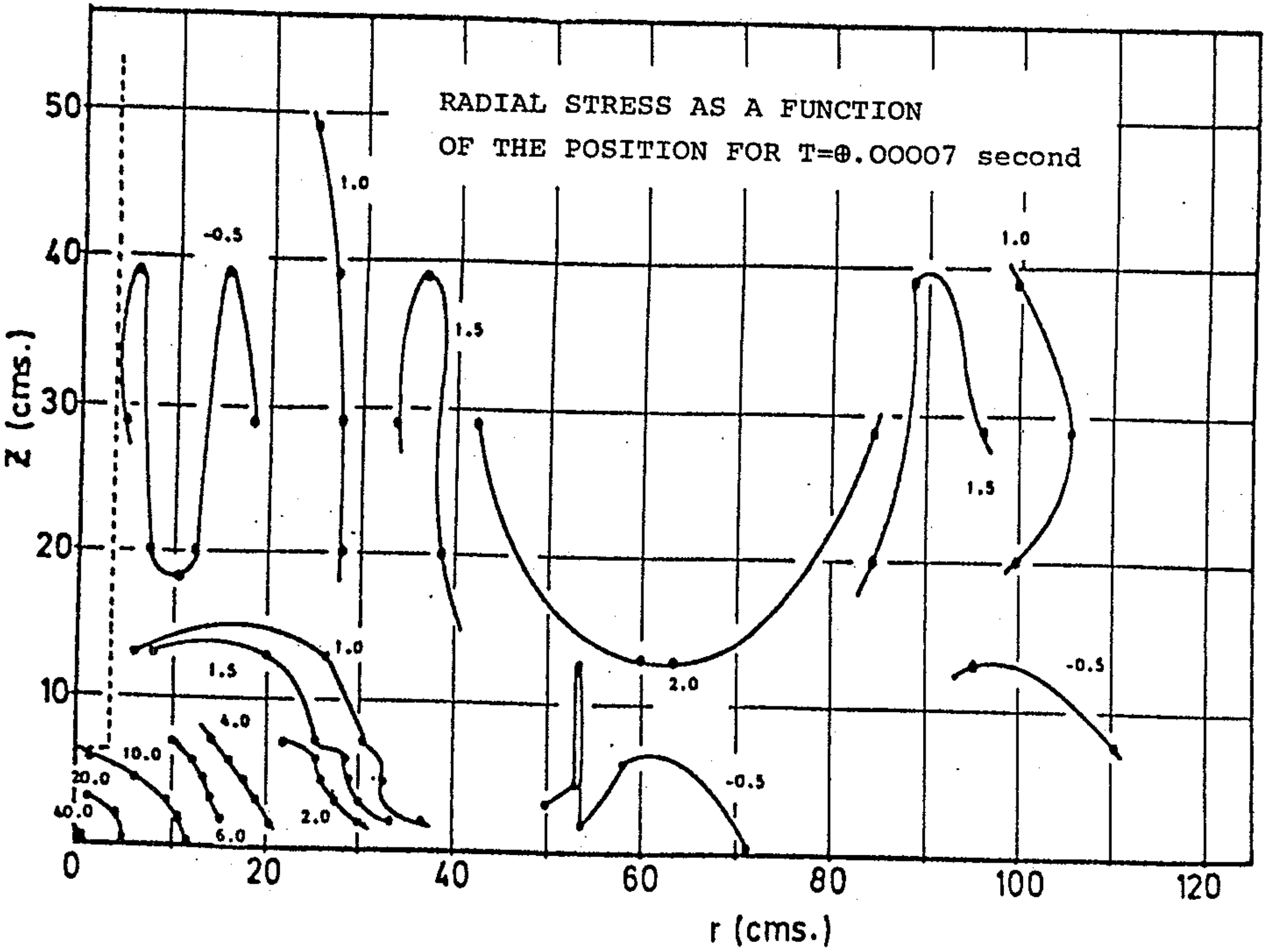

RADIAL STRESS AS A FUNCTION OF THE POSITION FOR T=θ.00007 second

Fig. 7

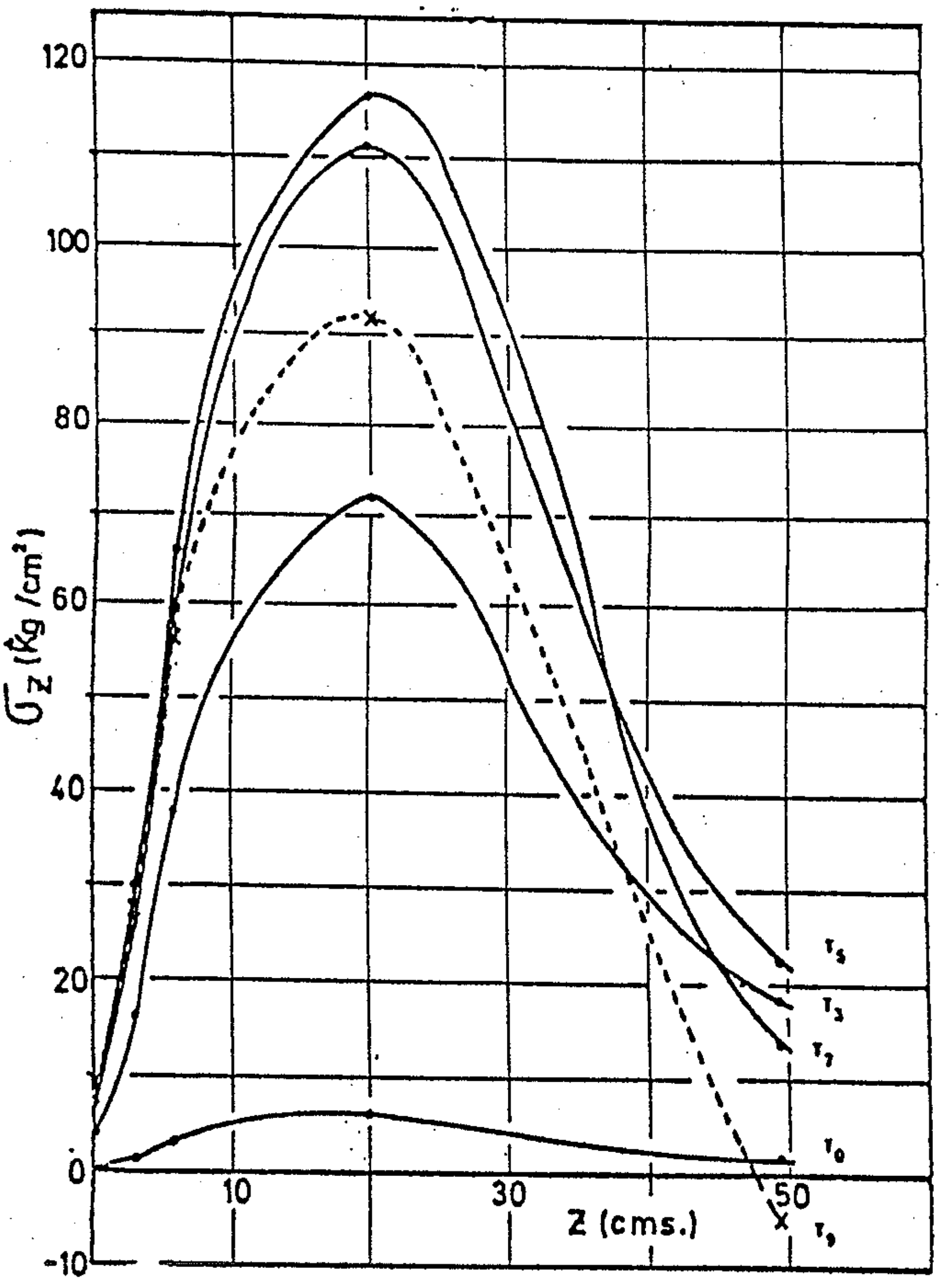


Fig. 8 STRESS σ_z FOR r= 4.45 cms. (CONTACT ZONE) AS A FUNCTION OF THE TIME

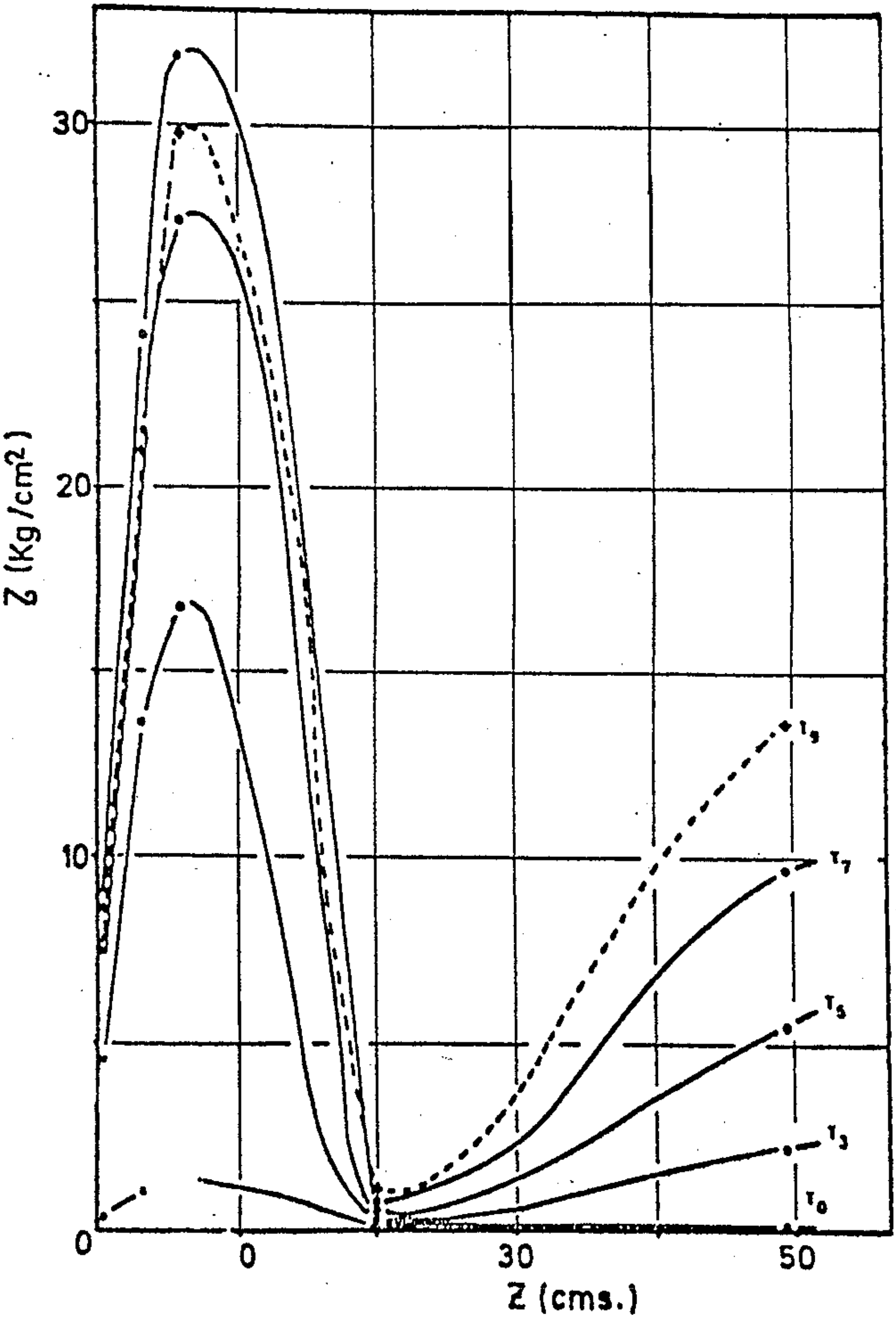


Figura 9.- : SHEARING STRESS FOR r= 4.45 cms. (CONTACT TONE)
AS A FUNCTION OF THE TIME