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EXPERIMENTAL RESEARCH OF CAUSES OF HIGH TUBE WELD CRACKS

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ABSTRACT. *The contributed paper acquaints with a part of experimental research of causes of degrading processes in welds of high tubes, so-called steelcentering of rotary kilns. The welds were made with automatic submerged - arc welding. Performed measurements of temperature fields and residual stresses in neighbourhood of a longitudinal weld have proved the necessity of change in regime of finish of steel centering geometric shape after welding. The utilization of localized heating method with subsequent quick - acting chilling appears essential for lowering of residual stress after welding. The work proves the dominant part of residual stress at connection failure of metal material of welded joints.*

1.Introduction

The rotary cement work kilns or rotary kilns for production of klinker are practically a thin-walled pipe with length to 150 meters, being composed from partial sections, so-called steel centering, being welded mutually together with circumferential welds. The diameters of steel centering are different, their diameter depends usually on designed output of a rotary kilns; the diameter of kiln at discharge end may be up to 4000 mm in general.

The thickness of centering plates may be selected in range from 20 to 50 mm; at kiln with output of 2000 t of clinker within 24 hours, as many as 100 mm.

Individual centerings are made from steel plates of ČSN 11 366.1 quality, i.e. from material being killed, with warranted mechanical properties in heat and with warranted fusion weldability. This material is practically coincident with the material of grade HI according to DIN 17155, being used at firm Krupp to analogic production, or with the material marked as MC-3 according to GOST 380-6, i.e. standard being used in Russia.

The plates for manufacturing of rotary kiln steel centerings are delivered from metallurgical plants in required forms, their edges are finished on needed shape of bevels for welding. The individual centerings are then made by centring operation and welding is being done exclusively automatically, as submerged - arc welding; thickness above 50 mm with electro-slag welding. Fusion faces, e.g. at plates with thicknes of 40 mm, are finished as symetric double V-butt welds (with reinforcement), with opening angle of 60 degs and with size of weld equal 5 mm. The inside bevel is welded at first, usually on three layers, and the outer bevel after 180° angular rotation, also on three layers.

Higher efficiency of electric arc at submerged arc - welding, thus higher heat concentration in surroundings of welded seam and higher rate of welding, raise among others higher heat drop between the point of molten pool and close surroundings of base material. This contributes to deformation of welded parts, in the given case to deformation of round figure of centered centering and to axial deformation (Fig.1). After welding this deformation was usually removed mechanically by means of so-called grooving between rolls of centering machine. This is done in cold state.

The described deformations due to welding are a result of stress, being evoked with liquid contraction of filler metal after solidification and with shrinkage of heated surroundings of base material. Cracks in spots of weld root can be found often by radiographic inspection of weld quality. The formation of crack adapts certainly the state of stress of welded centering to quasi static one, and if no further initiation occurs, the crack doesn't spread more. However, this condition isn't fulfilled at centering of rotary kiln, namely by reason of kiln exploitation. At production stage, the relatively long-lasting setting of states of stress after welding, is one of reason of that. The phenomenon, when no cracks in spot of weld root were found at X-ray radiographic inspection of centering weld in manufacturing plants, but in the same spot some cracks were detected before installation of rotary kiln at customer, with gamma-radiography (isotope Co60), thus by radiography with gradually lower sensitivity and detectability of defect, has been practically the most adverse case.

Such cases, calling forth more labour at external assembly and in the final result also entailling customer's mistrust, hawe evoked relatively extensive research programme. This programme has included, among others, the experimental determination of distribution of temperatures and stresses in weld surroundings within and after welding of centering and the determination of suitable technologic process for elimination of presented problems.

2.Measuring of temperature fields in base material of rotary kiln centering in the course of welding

The heat supplied at welding with a local source (electric arc) is concentrated on relatively small part of welded segment volume. This part is quickly heated up to high temperature. But the supplied heat is also dissipated, in part into welded segment, in part into surroundings; the temperature of base material in zone close to direct action of electric arc was measured on 1260 degrees of Celsius and it varies only little, due to good thermal insulation by fluxing agent.

It was needfull to track together with the movement of electrode also heat propagation in several points of base material simultaneously, and moreover it was necessery to track the courses of individual thermal cycles at given welding parameters, in dependence on time. The measuring of temperature has been performed at welding of longitudinal weld of rotary kiln centering (with outer diameter of 1280 mm, length 3520 mm and material thickness 40 mm, with plate quality according to ČSN 11361.1).

In points closest to weld PtRh - Pt thermo electric couples with compensating line were used, and in more distant points Fe-Co thermo-couples, without compensating line. The thermo-electric couples (6 pieces altogether) were placed at the centre of kiln jacket length, in a plane perpendicular to weld axis, on spacings of 25,40,70,120,190 and 300 mm from the axis of weld (Fig.2). The touches of thermo-couples with material were ensured with drilling of holes with diameter of 3 mm and with 5 mm depth. The sensors were inserted into there holes, riveted with copper wire (with diameter 2,8 mm) and heat shielded. The heat shielding of wire outlets of thermo-couples was ensured with ceramic beads and glass wadding.

The temperatures were measured at welding of the first layer of weld - root bead - internal side of bevel of double V butt weld, and at welding of the cover layer of weld outer side. The time for measurement has been chosen in the evening, when thermal fluctuations in production shop is minimal. Therefore the ambient temperature about 22 centigrade degrees didn't change during measurement.

The results of both measurements are in Fig. 3 and in Fig. 4, time of measuring was 1075s, cooling of warmest point passed through about 43 minutes. From both space diagrams (namely from Fig.4) they are unmistakable a great rise in starting temperature and a great thermal shock, with regard to short-term duration of this high temperature, and that without any expressive effect of preheating as much as 150 centigrade degrees (also at lower current load). The measurement has proved the affecting of proper weld by resultant internal stress, contingently also an exposure of base material to danger. So the measurement has proved a need to reduce at least the thermal gradient, e.g.with higher preheating temperature of weld and its surroundings at ensuring of subsequent slow-acting cooling. The experimental determination of residual stress after welding was a logical consequence of this measurement results.

3.Measuring of amount and variation of residual stresses after welding of centering longitudinal weld

For determination of residual stress after welding they have been used common strain-gauge roses 90 degrees with tremperature effect compensation by positioning of compensating strain gauges at every rose namely so that the strain gauge was bonded only with its part, and thermally insulated against environment. Besides this compensation it was verified the temperature effect on variation of "K" factor, which was less than one per cent. The arrangement of measuring points on kiln centering jacket is shown in Fig. 5. The strain-gauge rose was in every point directed into axial and circumferential directions. The points for bonding of strain gauges were ground about 1.5 mm below level of surrounding surface, with regard to enabling of positioning and final centering operation (grooving) for removing of deformation after welding. The experiment was performed on the same kiln centering, as in case of temperature measuring (chapter 2). The strain-gauge measuring has started one and half hour after ending of welding, thus in time when the joint became cold. The duration of measurement was long enough, so that the state of stress of the steel centering within course of longer time has been determined above all, as only after longer time they come into being the cracks, which havn`t been detected immediately after welding. With performed strain-gange measurement it was established which values the residual stress in welded centering has reached with given technology (i.e. submerged welding) how this stress is distributed (what kind are the fields of stress distribution), regarding to longitudinal axis of weld and also along periphery of body, further the dependence of stress course after time of welding and at last which effect the grooving of centering after its welding has on reduction of its residual state of stress, with regard to time of its welding.

Some results of measuring of maximum stress course at 300 mm spacing from weld axis are illustratively presented in Fig. 6 and Fig.7. The course of curves was continuous, without any abrupt fault, indicating sudden stress slacking e.g. by crack beginning. The weld was also inspected with X - ray examination and no its failure would be found. The stress maximum comes after about 5 hours after ending of welding; then peripheral stresses are largely higher then axial ones. The time, when ressidual stresses reach their maximum, is in accordance with previously presented practical piece of knowledge that weld failure doesn`t arise immediately after welding, but after longer time.

Greatest stresses arise nearer the centre of weld length, meanwhile stresses at the weld ends are lesser. But at the same time, the stresses at side of weld ending are higher.

With additional grooving of centering being done in cold state in order to reach of its round regular figure (with tolerances from plus 2 mm to minus 1 mm), the residual stresses at spacing of 300 mm from weld axis decrease essentially, more than one order.

The grooving being performed in periode till 5 hours after weld finishing, can improperly act on stress condition, as the critical time of the state of stress is at 4 to 6 hours after welding. However, the decrease of residual stress by grooving of centering at cold state,isn´t obviously pertinent from point of view of weld unrupture, even though the grooving as a technologie operation cann´t be excluded.

Unanticipately high maximum stresses nearly 3 hours after cooling of segment to ambient temperature, have to necessitate adaptation of steel centering welding technology.

4.Solution of problem and conclusion

The solution of being arisen problem of enhanced quality of the centering weld, which is acceptable both technological and economical, is a relatively extensive problematics, and with regard to extent of this paper, only some conclusions and resulting conclusions, being accepted by producer, are presented.

The heterogenity of weld joint and its close neighbourhood in base material, which is in every point different leads to account of treatment possibility with full annealing that adapts the casting structure within whole weld cross section.

However, a post-weld thermal treatment of welded rotary kiln steel centering by full annealing, eventually by stress relief annealing at least, demands suitable large volume furnance, relevant more expenses (stiffeners to prevent of round figure deformation, energy, and the others)and it doesn't enable to use this way at kiln assembly at future user in field. Thus it was necessary to choose another ways for removal reach, or if you like, reduction of state of stress of welded kiln steel centering.

From point of view of welded joint strength, it is important to limit residual internal stresses, while these above all, initiate the rise of microcrackes in critic points of cross section, especially on boundaries of crystals. By that time Vaughan and de Morton [3] and others have proved that the propensity to formation of cracks is dependent not only on cooling rate, but mainly on velocity of transition between temperature range of 150 centigrade degrees and 200 centigrade degrees, when cracks create.

The method of stress relieving with local heating (by flame) has the aim to equalize local internal stresses. Against another methods there is an advantage here in the possibility to perform this process at external assembling also. On principle, this method is the same as mechanical stress releasing is, only with that difference, that forces acting to stress equalizing are caused by heating of limited zones as much as to temperature approximately 200 degrees of Celsius. This method being succesfully proved in other heavy engineering branches (large tanks, ships, and the others) seems very convenient. The principle of residual stresses relieving with flame, consists in overlap of residual stress with another stress, being caused for a short time by relatively slight heating. With that, the plastic deformation is caused there in given locality, where the material yield point gets over. The fields of stress being caused by heating, decreases with cooling by water spray that follows immediately beyond heating. Then the resulting field of residual stress is substantially lower and more uniform.

With thermal zones in relative closeness along both sides of weld, they are caused the forces that at heating the weld in longitudinal direction extend and in cross direction compress it. At subsequentcooling the weld with longitudinal direction is being rather drawed together and with that, it is in cross direction extended. At used temperature around 200 degrees of Celsius, no influence of material microstructure comes.

A portable device i.e. a combination of torches and cooling system - spray (Fig.8) has been assembled to relieving residual stress by local heating. The whole device is being shifted along the weld with velocity,which is dependent (in case of steels with tensile strength lower than 500 MPa) on the thickness of welded segment, whereat the torches distance from surface and their spacing to weld axis is constant. The results obtained from so being chosed process are favourable and comparable with another processes, i.g. at use of classical full annealing (normalizing), or at use of induction heating. But last one is due to high electric power demand at external assembling practically nonutilizable.

References

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[3] Vaugham, H.G., de Morton, M.E.: *British WeldJourn.* 1 (1957),40.
[4] Kopřiva, M.: *ACTA Univ. Palacki, fak.rerum naturalium* 69 (1981),15.

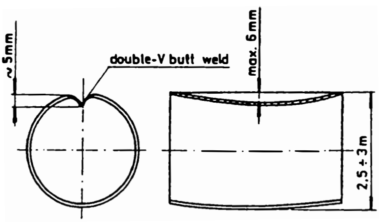

Fig.1 Example of shape and size of steel centering deformation.

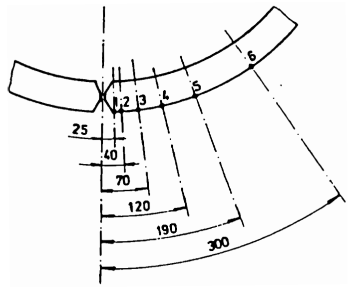

Fig.2 Layout of thermo-electric couples.

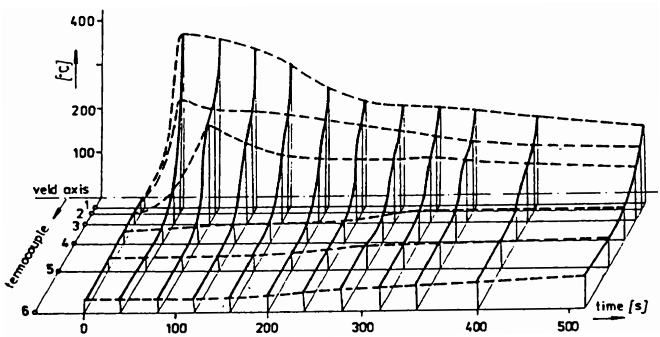

Fig.3 Field of temperature in surroundings of weld at welding of 1 st layer of weld (internal side of double V butt weld).

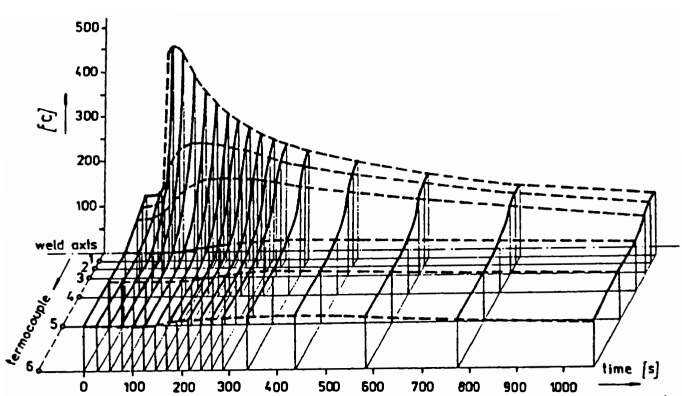

Fig.4 Field of temperature in surroundings of weld last layer (last cover layer of outer weld).

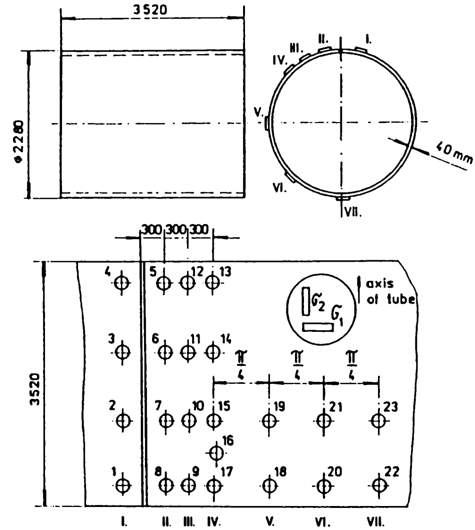

Fig.5 Layout of points for strain-gauge measurements on furnance steel centering.

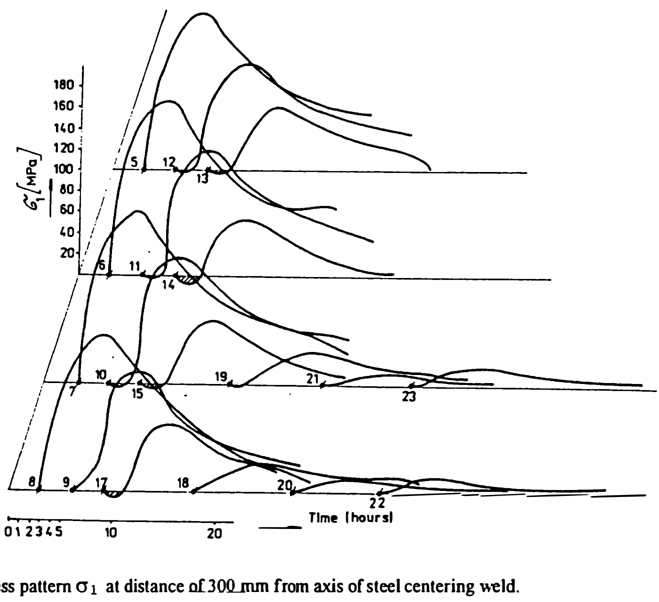

Fig.6 Stress pattern σ_1 at distance of 300 mm from axis of steel centering weld.

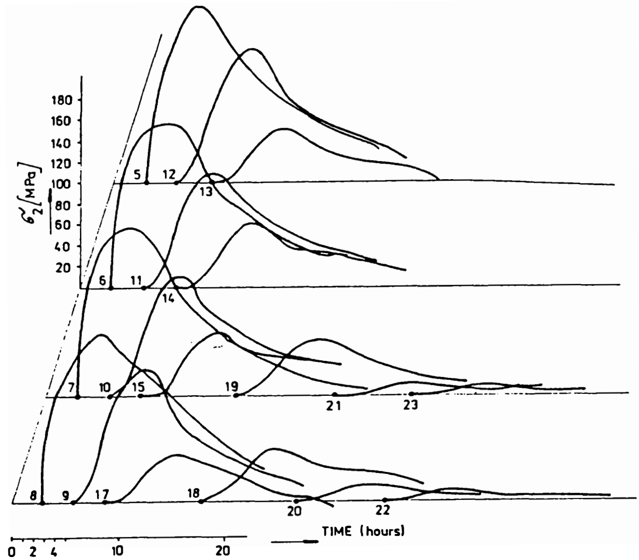

Fig.7 Stress pattern σ_2 at distance of 300 mm from axis of steel centering weld.

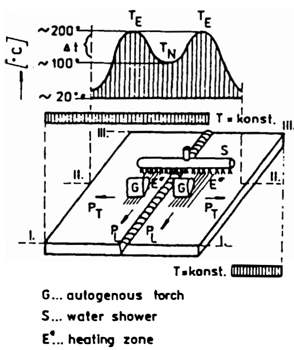

Fig.8 Functional chart of portable device for local heating with water spray.

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