CHANGES OF MECHANICAL PROPERTIES IN 0,5CR-0,5MO-0,3V STEEL WELDS AFTER LONG TERM EXPOSITION AT HIGH TEMPERATURES

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ZMĚNY MECHANICKÝCH VLASTNOSTÍ SVAROVÝCH SPOJŮ OCELI TYPU 0,5CR-0,5MO-0,3V PO DLOUHODOBÉ VYSOKOTEPLOTNÍ EXPOZICI

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Abstrakt

Nízkolegované CrMoV oceli pracují v energetických a chemických zařízeních při teplotách od cca 400 do 580°C tedy v creepové i podcreepové teplotní oblasti. Stanovení jejich zbytkové životnosti po uplynutí projektované doby provozu je závažným ekonomickým a technickým problémem. Doposud používaný model hodnocení zbytkové životnosti neuvažuje změny mikrostruktury, a tím ani mechanických vlastností, které dlouhodobá teplotní expozice vyvolá především v oblastech svarového spoje. U ocelí typu 0,5%Cr - 0,5%Mo - 0,3%V lze při provozních teplotách v podcreepové oblasti očekávat změnu mechanických vlastností vlivem sekundárního vytvrzení. V creepové oblasti dochází naopak k výraznému snížení původních pevnostních vlastností svarových spojů i základního materiálu.

Abstract

Low - alloyed CrMoV steels serve in power and chemical systems at temperatures between 400 and 580°C. This corresponds to the creep as well as sub-creep range. Estimation of residual life after projected exposition seems to be a major economical and technical problem. Up to the present time, the model used for estimation of residual life does not consider changes of microstructure influencing mechanical properties. Especially mechanical properties of welds are influenced by long-term high-temperature exposition. During exposition of 0.5Cr-0.5Mo-0.3V steel (15 128) at temperatures below the creep range secondary hardening can be expected. During exposition of this steel in the creep range, a considerable fall of yield strength and hardness of welds and also parent material is observed.

Key words: low-alloyed steel; CrMoV steel welds; the creep range; the sub-creep range; secondary hardening; coagulation; coarsening; additional precipitation; vanadium carbides.

1. Introduction

Chemical and power systems constructed from low-alloyed CrMoV creep resisting steel usually work at increased temperatures. These steels were developed for a max. service temperature of 580°C, i.e. in the creep range. In this case the decisive factor for dimensioning of material is creep strength at 10^5 or 2.10^5 hours. High yield strength at higher temperatures leads to the use this material at temperatures below 450°C, i.e. below creep range, see fig.1.

Fig.1 Creep strength and yield strength of some creep resisting steels

Estimation of residual life after projected exposition seems to be a major economical and technical problem. Necessary replacement of most stressed elements requires shutting down of equipment and consequently brings considerable economical losses. However, it is often observed that on reaching projected durability the equipment has not yet expended its real service life. The reason for this state is usually high safety coefficients of welded joints. Therefore, increased attention is being paid to the estimation of residual life for the last several years.

The usual recommended method for determining the extent of damage when estimating residual life of material exposed in the creep range is as follows:

visual control

deformation measurement

thickness and corrosion attack measurement

non-destructive methods

evaluation of surface film cavitation damage

control calculation using real operation parameters (temperature, pressure and time of exposition).

As this model of estimation ignores changes of microstructure, it does not allow reliable determination of residual life of power and chemical systems after long-term high-temperature exposition. Many important assignments concerning low-alloyed CrMoV steel show that high-temperature exposition significantly influences precipitation and dislocation contribution to microstructure hardening. A reduction of strength characteristics of material is observed. This fact is the consequence of a decline in dislocation density and coarsening of carbides.

The recommended method for determining the extent of damage when estimating residual life of material exposed in the sub-creep range is as follows:

visual control

deformation measurement

non-destructive methods

thickness and corrosion attack measurement

control calculation using real operation parameters (temperature, pressure and time of exposition).

During exposition of low-alloyed CrMoV steel in the below-creep range the mechanical properties of material are considered to be constant. Therefore, when processing control calculations, mechanical properties of "as received" material are used. This approach to the problem is however not correct. It's important to realise that after usual tempering of welds and parent material the microstructure is not in balance. This means that during long-term exposition in the sub-creep range a change of mechanical properties due to secondary hardening is to be expected. Hardening in welded joints is strongly dependent on the tempering temperature.

2. Changes of Mechanical Properties in 0,5Cr-0,5Mo-0,3V Steel Welds after Long-Term Exposition at High Temperatures below the Creep Range

Expected hardening of 0,5Cr-0,5Mo-0,3V parent material and its welds, after tempering at lower temperatures (650 - 680°C), is the result of secondary precipitation of carbides and carbonitrides from supersaturated solid solution. When exposed at temperatures below the creep range this fact causes degradation of material's plastic properties, represented by reduction of the impact strength value. On the contrary, ultimate strength and hardness of the material increase. Brittle cracking due to low plasticity and low impact strength is probable during shut-down and start-up of power equipment.

2.1 Experimental work

The parent material for experimental work was thick-walled pipe made from ČSN 41 5128 steel (DIN 14MoV 6 3, EN 12CrMoV 6-2). The root of the weld was performed using TIG technology; rest of the weld was carried out using SMAW technology. Welded joints were heat treated at three different temperatures - 650°C, 680°C and 715°C (8). Test specimens (prepared by cutting) were exposed at temperatures from 400°C to 550°C without stress. Time of exposition was set from 0,8 to 547 hours (8). These parameters were converted to work temperature of 400°C and 450°C for longer time period, using the Arrhenius formula. The value of activation energy was 292 kJ/mol (3).

Hardness measurement (HV10) in each zone of exposed welded joints was performed. Figure 2 presents measurement results in the normalized zone of the heat affected zone (HAZ) for exposition at 450°C.

Micro-hardness measurement was performed separately in ferrite and bainite. The shape of the sum curve corresponds identically to the curve obtained from hardness measurement. When comparing the above mentioned curves, the influence of ferrite and bainite on hardening of the whole workpiece is evident. Figure 3 presents the course of micro-hardness values in ferrite, bainite and the sum curve for normalized zone of HAZ (exposition at 450°C).

Fig.2 Hardness measurement, HAZ (normalized zone), exposition 450°C

Fig.3 Micro-hardness measurement, HAZ (normalized zone), exposition 450°C

2.2 Discussion

Micro-hardness measurement results (HV0,01) correspond satisfactorily to measurement of hardness (HV10). The hypothesis that hardening progresses initially in bainite and later in ferrite was confirmed. This fact is caused by higher density of dislocations in bainite. Dislocations represent defects of the crystal lattice, therefore, the heterogeneous precipitation of carbides begins here.

Impact toughness drops in the area of maximal hardness and rises in the field of coarsening of carbides (decline of hardness). Figure 4 shows two minimums of impact toughness at 500 and 20 000 hours.

The area of impact toughness minimum value is critical in terms of service reliability. When the temperature, for example during system shut-down, falls to room temperature, fracture within the weld is quite possible. If the ambient temperature falls to critical point, a brittle fracture appears.

Fig.4 Impact toughness (KCV) and hardness (HV10) measurement, weld metal, exposition 450°C, tempering 680°C

Presented hardening curves of CrMoV steel welded joints show that lower tempering temperature (650°C) causes considerably higher hardening during long-term temperature exposition below the creep range which in turn means increased danger of brittle cracking. From this point of view it is important to control the temperature for heat treatment of 0,5Cr-0,5Mo-0,3V steel welds very carefully. The presented course of impact toughness (Fig.4) shows the time of minimal values, not the absolute value of the minimum. The concrete value of this critical point depends on steel purity and can vary.

Hardening of 0,5Cr-0,5Mo-0,3V steel (caused especially by vanadium carbides precipitation) is controlled by vanadium diffusion velocity in ferrite. It is known that diffusion velocity increases with rising temperature; in other words, hardening is achieved in a shorter time.

3. Changes of Mechanical Properties in 0,5Cr-0,5Mo-0,3V Steel Welds after Long-Term Exposition at High Temperatures in the Creep Range

A welded joint in 15 128 steel (2) and its modeled zones of heat affected zone (HAZ) (3) were used for the study of changes of mechanical properties in 0,5Cr-0,5Mo-0,3V steel welds. To be able to observe structural changes developing in weld metal and parent material the specimens had to be annealed at temperatures of 575, 600, 650 and 700°C with no stress. The time of annealing was set between 2 and 10 000 hours (2). Specimens of modeled zones of the HAZ were annealed at temperatures from 600 to 650°C with no stress, with a time of annealing between 1 to 5000 hours (3). To obtain results of exposition times at temperatures 575 (2) and 550°C (3) the Arrhenius formula was used, with the value of activation energy at 292 kJ/mol.

3.1 Experiment Results and their Discussion

Changes of mechanical properties in weld metal and parent material 15 128 were observed by means of hardness and micro-hardness measurements in ferrite and bainite, see fig.5 and 6 (2). Changes of mechanical properties in modeled zones of HAZ were observed directly from obtained yield strength values, fig.7 (3).

Fig.5 Hardness measurement, basic (parent) material and weld metal, exposition 575°C

Fig.6 Micro-hardness measurement, basic (parent) material and weld metal, exp.575°C

Fig.7 Yield strength of modelled zones of HAZ, exposition 550°C,

a: overheated zone, b: normalized zone, c: partially recrystallized zone

Measured values show evidence of a considerable decrease in primary strength properties in welds and parent material during creep exposition. Hardness of weld metal and basic material begins to decrease considerably after approx. 1000 hours of creep exposition (temperature 575°C). At 200 000 hours hardness reaches almost half of its primary value. The curve of hardness measurement values corresponds with the micro-hardness values curve. Also, yield strength values in the modeled zones of HAZ begin to decrease after approx. 1000 hours of creep exposition. The decrease is most visible in the HAZ´s overheated zone, where the value of $R_{p0,2}$ falls to 60 % of its primary value in about 200 000 hours. The least visible decrease of Rp0,2 is in the partially recrystallized zone of HAZ.

The decrease of mechanical properties of 15 128 parent material and weld metal is caused by microstructural changes during creep exposition. Literary sources (3,4,5,6) discuss this in detail. Coagulation and coarsening of carbides and carbonitrides reduces the quantity of these elements per volume unit, while particle spacing increases. At the same time, the density of dislocations is reduced. Consequently, the value of dislocation and precipitation contribution to yield strength value is reduced. A relatively low reduction of the yield strength value in the partially recrystallized zone of HAZ is caused by the fact that coagulation and coarsening have already proceeded during welding. Comparison of the yield strength value of parent material before modeling the temperature cycles (Re=593 MPa) and the yield strength value of the modeled partially recrystallized zone of HAZ (Re=495 MPa) confirms this fact (3).

In order to assess residual life of equipment functioning in the creep range it is therefore necessary to use the real values of creep strength after a relevant time of temperature exposition and estimate its further possible decrease. For this reason, current yield strength values of assessed components are required and with the help of the curve in fig.8, the real value of creep strength and its further decrease can be assessed.

Fig.8 Relation between creep strength and yield strength at 20°C

The second possible option is to obtain small specimens (SSM method) to assess middle particle spacing λ. The curves, see fig.9 can be used to estimate the current creep value and its further decrease. This dependence is valid for parent material. In the case of welded joints these values would have to be obtained through measurement, otherwise, estimations published thus far can be used.

Fig.9 Effect of vanadium carbide distance on creep strength

4. Conclusion

Long term exposition of 0,5Cr-0,5Mo-0,3V steel and its welds at high temperatures in the creep and sub-creep range always causes changes of mechanical properties.

Additional precipitation of hardening particles during temperature exposition below the creep range leads to the hardening of welds as well as parent material.

Hardening increases considerably with of lower tempering temperatures after welding.

This hardening influences a decrease of plastic properties, especially the impact toughness values.

During evaluation of residual life of equipment exposed below the creep range, the measurement of hardness in parent material and also in every zone of welded joints is necessary.

Coagulation and coarsening of dispersed vanadium carbides leads to the increase of particle spacing per volume unit during exposition in the creep range. At the same time, the density of dislocations is reduced. These two mechanisms of microstructure degradation lead to the reduction of yield strength and creep strength of parent material as well as welds.

During evaluation of residual life of equipment exposed in the creep range, assessment of the current value of creep strength and its further decrease is necessary.

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