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EXPERIMENTAL RESIDUAL STRESS ANALYSIS OF WELDED BALL VALVE

Pavel Macura [1], František Fojtík [2], Radomír Hrnčář [3]

[1] Faculty of Mechanical Engineering, VŠB – TU Ostrava, Czech Republic, pavel.macura@vsb.cz
[2] Faculty of Mechanical Engineering, VŠB – TU Ostrava, Czech Republic, františek.fojtik@vsb.cz
[3] Faculty of Mechanical Engineering, VŠB – TU Ostrava, Czech Republic, radomir.hrncar@vsb.cz

Abstract – The paper is devoted to the issues of experimental analysis of residual stresses on the concrete part of pipelines – welded ball valve. A semi-destructive hole-drilling method was used for measurement, and experimental stress analysis and evaluation of residual stresses was made in accordance with the US standard ASTM E 837 – 01 [1], as well as with use of an integral method [2]. Residual stresses were measured both immediately after welding and after pressurising of the ball valve. This has enabled observation of the influence of pressurising on change of residual stresses in the neighbourhood of the welded joint. Results of measurement of residual stresses served for further assessment of strength and service life of this component.

Keywords: residual stress, hole–drilling method, ball valve

1. INTRODUCTION

Ball valves used on pipelines consist usually of the valve body, to which two flanges are fastened to. Connection of the body with flanges can be realised either by bolts or by welded joints. In case that the ball valve is situated underground, the welded ball valve appears to be more advantageous and it was moreover the customer's requirement. However, welding causes formation of considerable residual stresses in the neighbourhood of the welded joints, which must be taken into account at the assessment of the component service life. That's why it is necessary to know their magnitude and this can be best determined by measurement. Ball valves are after manufacture and assembly tested for strength and tightness by the pressure exceeding the nominal working pressure, which may influence the magnitude of residual stresses after welding. The paper contains results of measurements of residual stresses after welding and then after pressurising, as well as assessment of influence of pressurising on magnitude of resultant residual stresses.

2. METHOD AND RESULTS OF MEASUREMENTS

2.1. Measuring procedure

Measurements were made at the production plant both immediately after welding and cooling down, and after testing by pressurising. Object of measurements was the welded ball valve for the pipeline of diameter1200 mm, which is shown in the Figure 1.

Fig. 1. Welded ball valve.

The principle of the applied semi-destructive hole-drilling method is based on measurement of released strains in the neighbourhood of cylindrical holes, drilled at selected points of the investigated component. Released strains were measured by strain gauge methods with use of special rectangular strain gauges in the form of rosettes RY 61-120/S made by Hottinger, with length of strain gauge grids 1.5 mm. Cylindrical holes were drilled in centres of these rosettes successively in six depth steps, diameter and depth of the drilled holes were 1.5 mm. A static strain gauge apparatus P-3500 with switch of the measured points SB 10 made by Vishay was used for measurement of released relative strains.

Positions and marking of strain gauge rosettes in the neighbourhood of the welded joint after welding and prior to pressurising are shown in the Fig. 2. We chose the distance between the measured points 10 mm. Due to dimensions of substrates of strain gauge rosettes the rosettes had to be glued in two rows.

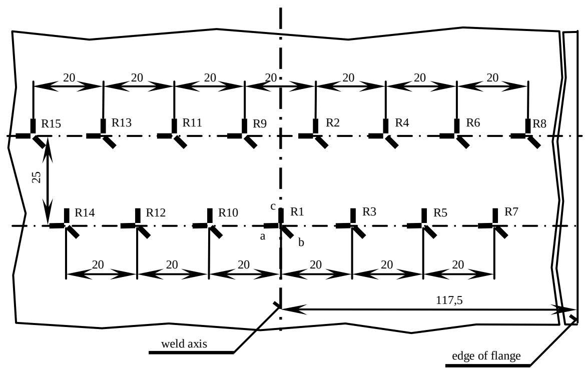


Fig. 2. Places of measurement.

Detailed location of rosettes on the welded joint is shown in the Fig. 3.

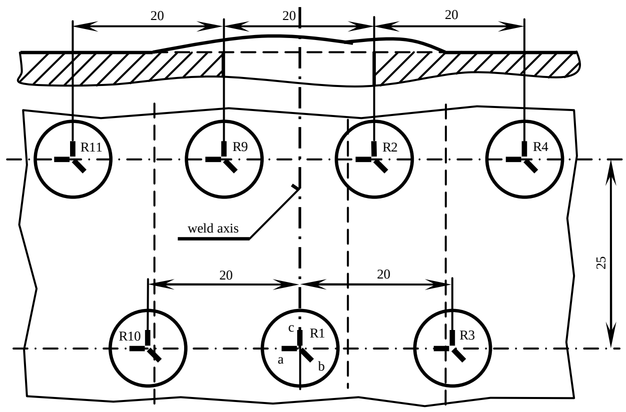


Fig. 3. Places of measurement around weld axis.

Similar arrangement of strain gauge rosettes was applied also at measurement of residual stresses after pressurising, i.e. that measurement was made at fifteen points after welding and at fifteen points after pressurising.

2.2. Methods of evaluation

Several methods were developed for evaluation of magnitude of residual stresses from the measured released relative strains. They are based on theoretical solution of tension on the neighbourhood of the load-bearing cylindrical hole developed by Kirsch [3]. Methods of evaluation of residual stress can be divided into two groups containing these results:

a) value of the mean residual stress along the depth of the drilled hole, evaluated from the measured released relative strains at the final depth of the hole

b) course of the residual stresses along the depth of the drilled hole, evaluated from the measured released relative strains at individual steps during drilling of the circular hole.

Evaluation of mean values of residual stresses can be made in accordance with the US standard ASTM 837-01 [1], or with methodology of the company Hottinger [4]. The courses of residual stresses along the depth of the drilled hole were evaluated by integral method, procedure of which is described in literature [2]. Another possibility is e.g. us of methodology published in the publication of the company Vishay [5]. In case of the measured ball valve both the mean values and courses of residual stresses along the depth of drilled holes were evaluated.

Evaluation of residual stresses was made on assumption of validity of the Hooke law in the whole range of the measured relative strains. If the evaluated residual stress is higher than the yield value, it means that plastic deformation has occurred at the investigated point and that residual stress at that point is close to the stress at the yield point of this material.

2.3. Measurement results

Results of measurements and evaluation of the mean values of residual stresses in the neighbourhood of the welded joint after welding and before pressurising are given in the Fig. 4.

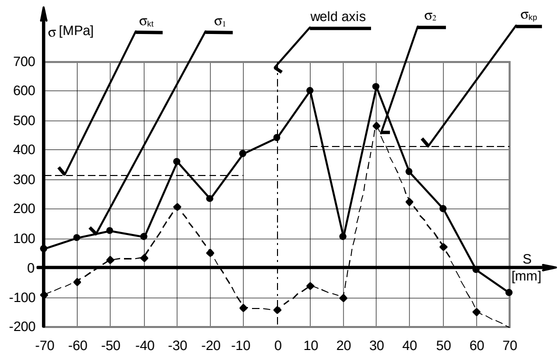


Fig. 4. Main residual stresses before pressuring.

Courses of both main residual stresses up to the distance of 70 mm to both sides of the welded joint between the body and flange of the ball valve are plotted here. The diagram shows also values of the yield point of materials of the body σ_{kt} and the flange σ_{kp}. It is evident, that at the very neighbourhood of the welded joint one main stress is tensile and the other one is compressive, while at somewhat distant areas both main stresses are tensile. At certain distance from the welded joint at the side of the flange both main residual stresses pass to compressive values.

Figure 5 shows plotted courses of mean values of the main residual stresses measured and evaluated after pressurising of the ball valve. Marking and courses of stresses are similar to those in the Fig. 4, only their magnitude is different.

Stress condition in certain area of the load bearing body is given by the tensor field, which cannot be characterised unequivocally by a single value, as is the case of the scalar field. That’s why there is a problem at the effort of evaluation of the influence of pressurising on the residual state of stress – which quantity should be used for this evaluation. Approximate comparison is perhaps possible by comparing the values of reduced residual stresses, calculated on the basis of the strength hypothesis HMH.

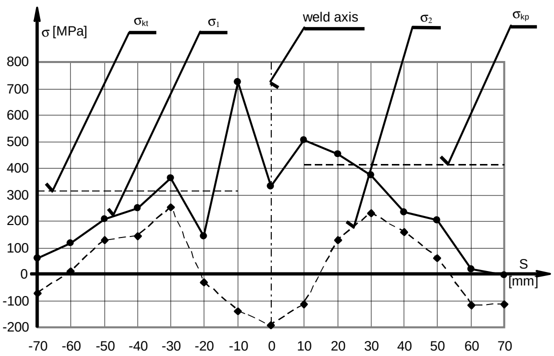


Fig. 5. Main residual stresses after pressurising.

Result of such comparison is plotted in the Fig. 6. Continuous line shows here the course of the reduced residual stress σ_{rs} before pressurising, while dashed line shows the course of the reduced residual stress σ_{rt} after pressurising. Drop of residual stresses as a result of pressurising is not distinct, at the side of the flange it was on average 24 %.

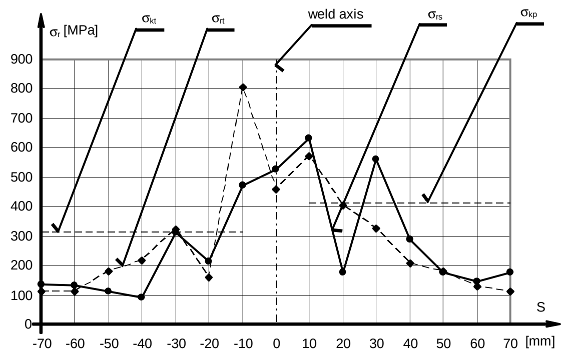


Fig. 6. Reduced residual stresses.

The pressurising of ball valves is provided subsequently. The whole assembled and connected ball valve is sunk into testing water pool. It is loaded by overpressure, which is 50% higher than nominal pressure. The product tightness, strength and this time even the residual stresses were tested.

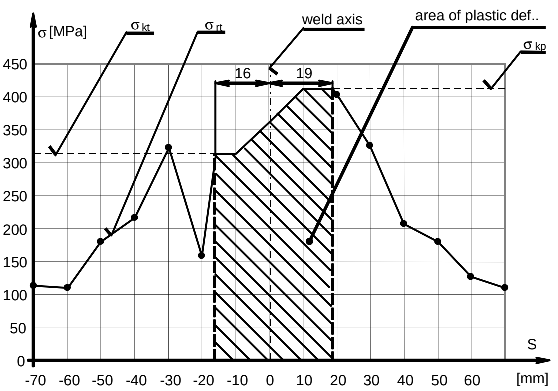


Fig. 7. Area of plastic deformation.

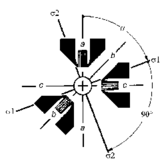
Process of welding causes high residual stresses often even in the zone of plastic deformations. In the Fig. 7 the area, in which plastic deformations remain even after pressurising, is hatched.

The applied procedure of successive hole-drilling and measurement makes it possible to evaluate also the gradients and courses of residual stresses under the surface of the measured component.

The results of residual stress measurements are processed in the form of test report, Fig. 8. The test report includes heading, table and graph. The heading determines the basic data about the measurement and measured material. The measured values of relaxated strains and evaluated residual stresses are given at the table. The distributions of main residual stresses commensurate with the drilled depth are described at the graph. The test reports are the basic documents of legislative reports for customers.

The test report from residual stress measurement

Place : R12 - Ball valve
Hole diameter : 1,6 mm
Rosette : RY61 1,5/120S
Material : 11503.1
E : 2,10E+05
μ : 0,3



Z	Z/D	εa	εb	εc	σ1	σ2	α	σ r	σ t	σ red
mm	-	μS	μS	μS	MPa	MPa	°	MPa	MPa	MPa
0,254	0,050	7	8	30	-48,6	-170,4	21,2	-154,4	-64,6	152,0
0,508	0,100	-7	-32	29	52,2	-109,6	33,7	-59,9	2,5	143,0
0,762	0,149	-29	-68	4	88,2	-43,5	36,7	3,6	41,1	116,2
1,016	0,199	-39	-94	-27	104,1	-5,5	42,2	44,0	54,7	107,0
1,27	0,249	-47	-96	-35	100,2	13,8	41,9	52,3	61,6	94,1
1,524	0,299	-45	-97	-38	96,5	15,8	43,2	53,6	58,7	89,7

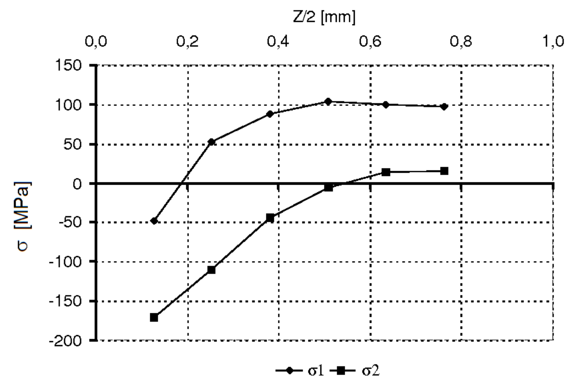


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Fig. 8. The test report form residual stress measurement by means of incrementally hole-drilling strain gage method.

3. CONCLUSIONS

The paper describes shortly the results of measurement of residual stresses in the welded ball valve. The aim of the measurement was to determine the magnitude of results after welding and to assess their influencing by the test pressurising. Process of pressurising is currently used for reduction of residual stresses, however, in those cases the applied pressures are much higher than in case of the measured ball valve.

Measurement was made with use of a semi-destructive hole-drilling method, which makes it possible to measure also the courses of residual stresses under the surface of the component. Procedure and method of evaluation are given by the US standard ASTM E 837-01, which is probably the most widely used method for measurement of residual stresses.

One of the factors, which must be taken into consideration at assessment of highly loaded components, is also the magnitude of residual stresses after technological production process. Results of realised measurements serve as a basis for evaluation of the resultant load and service life of the welded ball valves.

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