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A Study on Determination of Residual Stresses by Hole Drilling Method in Welded Tubular K Joints

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Abstract:

Residual stress can be favorable or detrimental to some components depend on its type. Generally, compressive residual stress can improve the quality of the component and tensile residual stress can cause detriment to components. On welding parameters, types, sequence, component type, component materials and component sizes the welding residual stress distribution varies in different locations. Due to stress concentrations, welding imperfections and tensile residual weld stresses tubular arch bridges are at risk to fatigue problems. These type of structural bridges are composed of circular hollow section profiles welded together in tubular joints. This paper describes the determination of residual weld stresses in K-joints with the incremental hole-drilling method. The residual stress distribution can be used to determine fatigue crack behavior and fatigue lifetime more precisely.

The incremental hole -drilling method is used to measure residual welding stresses on two similar K-joints. The residual stress measurements performed with Strain gauge rosettes and are attached to the test surface and with the milling guide, a small hole is drilled through the center of the strain gauge rosette. Strains at incremental depths are measured and the residual stresses are calculated according to ASTM E837-13a.

This review paper provides the information of welding residual stress and their distribution tubular K-joints. This paper can help and giving idea to researchers on planning their welding work with a minimum value of residual stress.

Keywords — **Residual Stresses, Hole Drilling Method, Welded Tubular K Joints.**

I. INTRODUCTION

Residual stress is the stress that exist within a component when there are no external load are applied to it. Nowadays, welding had been applied in many field such as construction, piping, shipbuilding, aircraft and aerospace, automotive, railroad, farm equipment, home appliances, mining equipment, computer components and construction equipment. Welding is a joining process of two or more metal parts to form a single product and it is used to produces a secure and strong joint that is stronger than other methods of bonding metals. Welding is a process that involves localized heat generation from moving heat source.

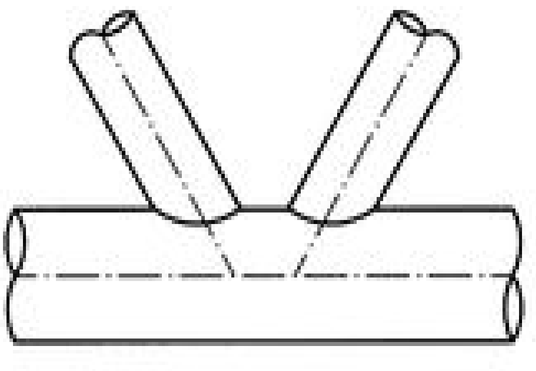


Fig.1. Tubular K Joint

Due to the localized heating and rapid cooling residual stress exists in welded component. In welded component tensile residual stress may lead to crack initiation to the component, while compressive residual stress can improve the component quality.

Tubular steel arch bridges are highly appreciated for their aesthetic value. The use of hollow tubes with circular sections and the connections in the nodes where several tubes meet ensures a smooth shape. These structures are composed of several steel bridge joints where larger primary tubes are welded together with smaller secondary tubes. The fatigue strength is important because the welded joints introduce high stresses near the weld toe of the joints. These high stresses are the result of the welding process and the influence of geometric discontinuities on the flow of the stresses, resulting in possible fatigue failure.

The welding process introduces residual welding stresses near the welded tubular joints. Residual stress distributions can have large stress gradients due to their non-uniform behavior. These stress gradients make it necessary to perform residual stress measurements in order to estimate the influence on the fatigue strength of the welded joints in tubular arch bridges. The fatigue strength can be increased by the presence of compressive residual stresses. Tensile yield stresses tend to open cracks and have a detrimental influence on the fatigue crack propagating under cyclic traffic loadings on the bridge. Residual stress can make the difference between a fatigue micro crack to grow or not. Moreover, residual stresses can also influence the rate of crack propagation, since the tensile residual stress field is often associated with a shorter fatigue life. Therefore, knowledge of the distribution of the residual welding stresses requires for accurate fatigue design of fatigue-sensitive bridge components.

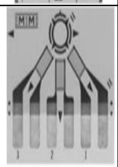
In this paper, the residual stress distribution of tubular K- joints are determined with the incremental hole-drilling method. Therefore, a small hole is drilled through a strain gauge rosette which is attached to the primary and secondary tubes of the joint. During the drilling, strains are recorded and these are used to calculate the residual stresses. Several measuring points are chosen on the tubular K joint and a residual stress distribution is established.

Nomenclature	
D	Diameter of primary tube
d	Diameter of secondary tube
L	Length of primary tube
l	Length of secondary tube
T	Thickness of primary tube
t	Thickness of secondary tube

II. INCREMENTAL HOLE-DRILLING METHOD

The incremental hole-drilling method is a semi-destructive measuring method where a small hole is drilled into the test material through the center of a strain gauge rosette. These strain gauge rosettes are used to measure the relieved surface strains caused by the introduction of a hole that is formed by drilling in a series of small steps. The measured strains are used to calculate the residual stresses according to the principles specified in ASTM E837-13a and this test method only applies assuming linear-elastic material behavior.

In order to obtain reliable measurements, a certain sequence of actions must be respected. First, the surface has to be prepared. The surface is prepared using silicon carbide abrasive paper to ensure adequate microscopic roughness to promote secure gauge bonding. Before attaching the strain gauge rosette, the surface has to be neutralized and degreased. For the residual stress measurement on the tubular K joints, three different types of strain gauge rosette configurations were used. Strain gauge rosette type EA-06-125RE-120 is used to drill a hole with an approximate diameter of 4mm up to a depth of 2mm. Measurements for a hole with an approximate diameter of 2mm with a depth of 1mm are performed with strain gauge rosette types CEA-06 -062UL-120 and CEA-06-062UM-120 for measurements close to a weld or edge. The different types of strain gauge rosettes and their dimensions are shown in Table. 1.

GAUGE PATTERN AND DESIGNATION Insert Desired S-T-C No. in Spaces Marked XX.		REST in OHMS	DIMENSIONS					
			Gauge Length	Grid Line Dia.	Typical Hole Dia.		Matrix	
					Min	Max	Length	Width
EA-XX-125RE-120		120±0.2%	0.125	0.404	0.12	0.16	0.78	0.78
Ea-XX-125RE-120/SE		120±0.4%	3.18	10.26	3.0	4.1	19.8	19.8
			Larger version of the 062RE pattern					
CEA-XX-062UL-120		120±0.4%	0.062	0.202	0.06	0.08	0.50	0.62
			1.57	5.13	1.5	2.0	12.7	15.7
			Fully encapsulated with large copper-coated soldering tabs. Same pattern geometry as 062RE pattern					
CEA-XX-062UM-120		120±0.4%	0.062	0.202	0.06	0.08	0.38	0.48
			1.57	5.13	1.5	2.0	9.62	12.2
			Fully surrounded with large copper-coated soldering tabs and special trim alignment marks. Trim line spaced 0.068 in (1.73) from hole centre. Limitation may exist in data reduction equation.					

After the attachment of the strain gauge rosette to the surface, the residual stress measurements can start. The RS200 Milling Guide is used to evaluate the residual stresses near the welded K joint. The drill is positioned right above the center of the strain gauge rosette with the microscope of the milling guide. To begin the strain measurements, zero depth has to be established first. Therefore, the test surface material has to be exposed by drilling only through the material of the strain gauge rosette.

The zero depth strain measurement indicates the beginning of the incremental hole-drilling. A series of increments is drilled into the specimen and at each increment; the depth of the hole and the strain relaxation at each gauge is recorded. The relaxed strain data is used to calculate the residual stresses in the plane normal to the hole axis, using calibration constants appropriate for the used strain gauge rosette.

III. Experimental Setup

There are two different test specimens used for the residual stress measurements. Both test specimens are K-node tubular joints but with slightly different dimensions. These are constructed with construction steel S355 with a yield stress equal to 355MPa. A sketch of the test specimen is shown in Fig. 2 with an indication of dimensions which are listed in Table 1. For the two different test specimens, only the length of the secondary tube differs.

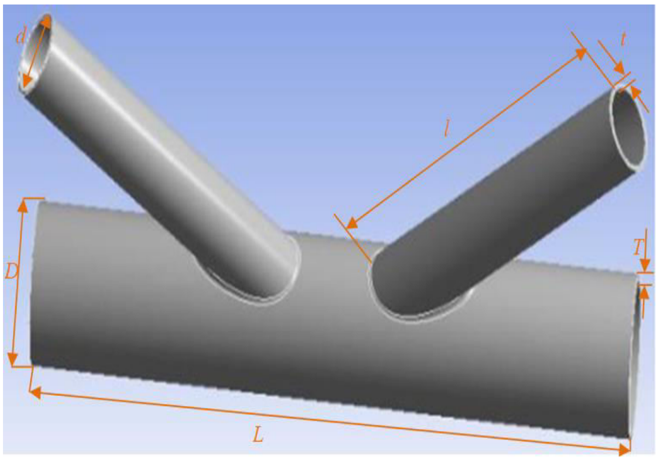


Fig. 2. Sketch of test specimen

TABLE 1.
DIMENSIONS OF TEST SPECIMEN

Test Specimen	D(mm)	T(mm)	L(mm)	d(mm)	t(mm)	l (mm)
1	210	15	370	110	10	250
2	210	15	370	110	10	250

On test specimen 1, the drilling depth is 1mm while the drilling depth for test specimen 2 is 2mm. For both test specimens, the circumferential and axial residual stresses will be investigated in function of the distance to the weld and the depth below the surface. The locations for the hole drilling on the two test specimens are predominantly similar. Some small difference in test location on the two different nodes exists due to practical considerations. The strain gauges for test specimen 2 are larger and minimal distances between drilling holes have to be respected, resulting in larger intermediate distances for test specimen 2. The measurement locations for the hole drilling are shown in Fig. 3(a) for test specimen 1 and Fig. 3(b) for test specimen 2. The distance relative to the center of the weld for both the horizontal and vertical direction is shown in Table 2 for test specimen 1 and Table 3 for test specimen 2.

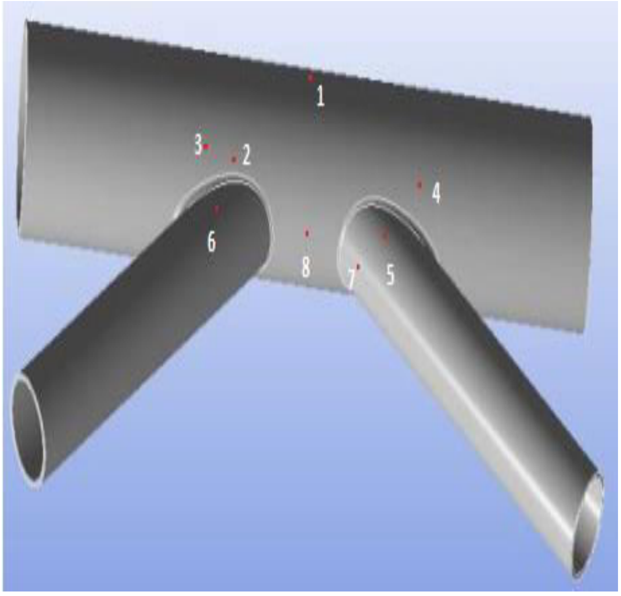


Fig. 3. Measurement locations for (a) test specimen 1

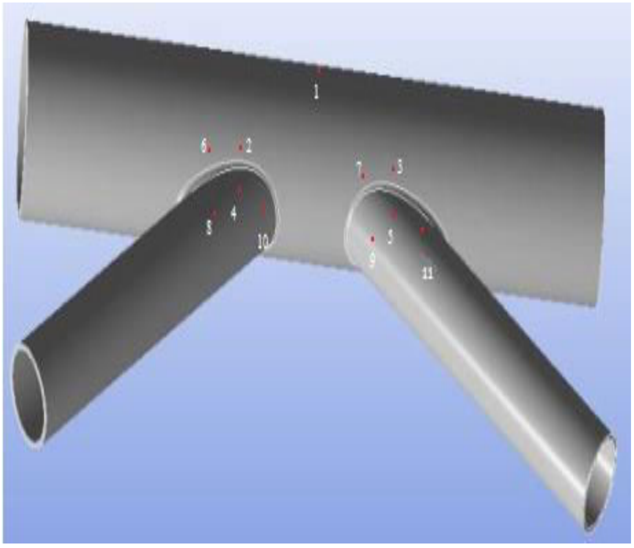


Fig. 3. Measurement locations for (b) test specimen 2

TABLE 2.
DIMENSIONS OF TEST SPECIMEN 1

Measurement location	Vertical distance to weld (*mm*)
1	160
2	3
3	15
4	25
5	3
6	10
7	25
8	50

TABLE 3.
DIMENSIONS OF TEST SPECIMEN 2

Measurement location	Vertical distance to weld (*mm*)
1	160
2	15
3	8
4	13
5	12
6	25
7	12
8	40
9	60
10	40
11	15

To determine the zero depth as accurately as possible, the increments are chosen as small as possible in the beginning. This minimal depth step for the micrometer of the milling guide is 0.025mm. Once the zero depth is reached, the increment steps are increased gradually. ASTM provides calibration coefficients for 20 increments but it is recommended to make more increments and smooth it to 20 increments.

IV. TEST RESULTS

Strains are recorded during the drilling procedure for the different measuring points. A calculation software H-DRILL is used to convert the recorded strains of a strain gauge rosette into axial and circumferential residual stresses according to the principles of ASTM E837 -13a. The residual stress distribution into the depth of the material is obtained for all measuring points where there are strain gauge rosettes positioned. To evaluate the residual stresses caused by welding the primary tube of the K -node joint to the secondary tubes, a single representative residual stress value is chosen for each strain gauge rosette. The residual stress distribution into the depth of the material for each strain gauge rosette is studied in order to find the most suitable residual stress value.

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V. CONCLUSION

The welding residual stresses for a tubular K-node joint are experimentally determined with the hole-drilling method. There are two similar test specimens used. For the first test specimen, the hole-drilling procedure was executed until a final hole depth of 1mm was reached while the final hole depth of the second test specimen is 2mm. The results for both specimens are compared and it is opted to prefer the measurements of the second test specimen. The confidence intervals are for most measuring points smaller and more measurement results into the depth of the material are available, eliminating the uncertain near-surface stresses.

A residual stress distribution perpendicular to the weld for both the axial and circumferential direction is obtained. Similar trends of the stress distribution are found for the residual stresses in both directions. In the axial direction, there are tensile residual yield stresses near the weld toe and smaller tensile residual stresses at a larger distance. In the circumferential direction, there are tensile residual stresses smaller than 50% of the yield stress present near the weld toe and at a larger distance, the stresses are close to zero. However, more research will be necessary to verify the distribution of the residual stresses of a welded K-joint, especially for the secondary tube.

The presence of tensile residual yield stresses near the weld toe of tubular K-node joints, can affect the fatigue lifetime of these joints. Tensile yield stresses tend to open cracks and have a detrimental influence on the fatigue crack propagating under cyclic traffic loadings on the bridge. Residual stress can make the difference between a fatigue micro crack to grow or not. Moreover, residual stresses can also influence the rate of crack propagation, since the tensile residual stress field is often associated with a shorter fatigue life. Therefore, knowledge of the residual stress distribution is essential to accurately estimate the crack development under fatigue loads. With the hole-drilling method, a residual welding stress distribution can be obtained. The knowledge of this distribution is essential to determine the effect of residual stresses on fatigue life behavior for K-nodes in tubular arch bridges.

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