Journal of Materials Processing Technology 220 (2015) 215–223

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Numerical and experimental verification of new method for connecting pipe to flange by cold forming

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ARTICLE INFO

Article history:
Received 22 May 2014
Received in revised form 9 January 2015
Accepted 16 January 2015
Available online 31 January 2015

Keywords:
Flange
Cold forming
FE simulation

ABSTRACT

In this paper a new method of connecting pipe to flange without welding is presented. This method is a cold forming process that is based on plastic expansion/deformation of the pipe into a modified standard flange by use of a cold forming tool. The method is patented by Quickflange Technology AS and represents a highly feasible alternative to welding. The successful use of the method requires the ability to predict dimensional and stress/strain characteristics of the pipe and flange after the connection process in order to evaluate the connectivity to the adjacent flange as well as the leak tightness. In addition the ability to predict the process force during the connection process is needed in order to control the process and design the hydraulically actuated cold forming tool. It is shown that it is possible to simulate this process using the finite element (FE) method and achieve a good accordance with experimental results. For this purpose a non-linear FE model of the flange, pipe and forming tool is developed and analyzed using Abaqus.

Experimental work, including tensile material testing and Quickflange joining tests were carried out for material model calibration and Quickflange process model validation, respectively. The FE model results are in good accordance with experimental observations in terms of actuation force for the process, deformations and strains of pipe and flange during and after the process. It is concluded that the developed FE model is a useful tool for simulating the presented process within reasonable computational time as long as careful considerations are given to model complexity, material parameters, friction, and pipe geometry tolerances.

1. Introduction

Welding has been the technology of choice for pipe-flange connections, however, a major problem in offshore oil and gas production is the inability to weld in the presence of gas leading to extensive down time during maintenance. To avoid this problem the Quickflange technology has been developed based on plastic expansion/deformation of the pipe into a modified standard flange by use of a cold forming tool and has been successfully applied to pipes in the diameter range 0.75 to 14 in. The Quickflange process set-up is illustrated in Fig. 1.

The pipe is positioned inside a modified flange with grooves. Inside the pipe, a segmented expansion tool is held fixed in axial direction by means of a retainer. The expansion tool consists of a number of segments that together forms a cylinder with an inner conical shape. During cold flanging, hydraulic pressure drives a piston connected to a cone, into the segments. This causes the segments to separate in tangential direction and, simultaneously, dilate in radial direction. The radial dilation forces the pipe to cold deform into the groves of the flange. The cone is driven by a hydraulically actuated double acting piston that is also used to pull the cone back and allow the expansion tool to retract after the cold forming is complete. Therefore, the main components of the cold forming tool are the retainer, the conical expansion tool (segments), the cone and the hydraulically actuated piston.

It is expected that the mechanical flange to pipe joining technology, based on cold deformation of the pipe, will make installation, inspection and maintenance of pipelines safer and more cost

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http://dx.doi.org/10.1016/j.jmatprotec.2015.01.018

Nomenclature

a	cone angle
x	axial displacement of cone
r	radial displacement of segment
Δr	radial displacement of pipe
P	hydraulic pressure in cold forming tool
A	piston area of cold forming tool
σ_r	true stress
ε_p	plastic strain
ε	strain
ε_T	tangential strain along flange periphery
$\varepsilon_{\mathrm{NF}}$	tangential strain along flange neck
F_R	radial force between pipe and segment extracted from finite element analysis
N	normal force between segment and cone
N_A	normal force between retainer and segment
μ	friction coefficient between cone and segment
μ_a	friction coefficient between retainer and segment
μ_p	friction coefficient between pipe and flange and between pipe and segment
T	step period in finite element analysis

effective than with current state-of-the art flanging technology for offshore applications. It is also expected that the technology is scalable for use with larger pipes and flanges. However, due to the complex nature of the connection process the scaling is non-trivial. It requires a better fundamental knowledge about, and understanding of, the elasticity and plastic deformation of the metals and alloys used in the pipe and flange.

Mori et al. (2013) survey joining by plastic deformation and describe force-fit joints that depend on plastic deformation of one joint member and, subsequent, residual contact pressure due to elastic spring back of both joint members. They also point out that one of the main disadvantages of plastic deformation based processes is lack of calculation methods and standards. Marré et al. (2008) describe joint manufacturing of tubular members and divide them into force-fit and form-fit joints. In the latter case the joint load is mainly transferred as normal forces and the axial load carrying capability normally compares favorably with that of a force-fit joint. The current pipe flange connection may be considered a form-fit joint. A recent survey by Groche et al. (2014) mentions the two most common processes used in forming of tubular form-fit joints: hydroforming and electromagnetic pulsing. In the current process the expansion of the pipe is generated mechanically which allows for high forces but also introduces the challenge of applying the radial expansion pressure uniformly.

In order to predict the process input most research combines either analytical or numerical studies with experimental verification. As an example of an analytical approach Gies et al. (2012) introduced expressions that estimate the hydraulic pressure required to bulge the inner tube into the groove in hydroforming. Numerical approaches may be found in a number of recent works on tubular form-fit joining based on electromagnetic pulsing. This includes Park et al. (2005) that investigated the influence of the groove design on both axial and torsional load carrying capacity of aluminium–steel joints. They combined experimental work and FEA to set up design rules for groove geometry. Similarly, Vanhulsel et al. (2011) verified the increase in axial load carrying capacity caused by an extra groove in steel-steel and aluminium–steel connections by means of experiments and FEA.

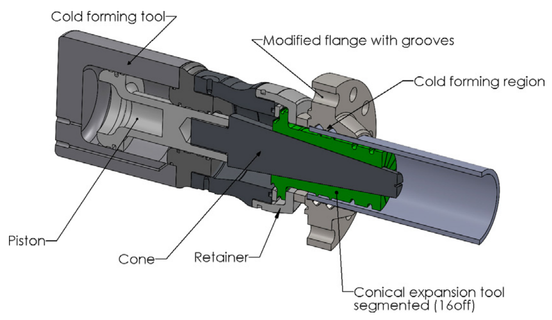

Fig. 1. The main components employed in the Quickflange process.

Table 1
Type of sensor used in experimental set up.

Parameter	What to measure	Number and type of sensor
V1	Hydraulic pressure in tool head	1 off HBM pressure transducer1-P3IC/1000BAR
V2	Axial displacement of cone	HBM inductive displacement transducer
V3	Tangential strain at periphery of flange	4 off single grid strain gauges type TML FLA-5
V4	Radial deformation of pipe during process	4 off LVDT type RDP A5 200
V5	Axial and tangential strain in flange	4 off 90° strain gauges type TML YEFCA2
V7	Strain in Flange groove	2 off 60° strain gauge rosettes. Type TML YEFRA2

As an example of mechanically induced pressure Qi et al. (2014) presented combined experimental work and FEA of a rotary swaging process joining copper-copper tubes setting up design rules for the positioning of the die tools relative to the tubes. All of the above papers put forward reduction in design weight and energy usage as the main advantages associated with form-fit joints. The main advantage of the cold flanging process of Quickflange AS is, however, not weight reduction or strength increase of the joint but simply the avoidance of welding. Therefore, the main focus of the present paper is not on the groove design but whether the process can be satisfactorily predicted by means of the FE Method. A reliable numerical model is of importance and would help in reducing the trial and error operations in the selection of tools and processes design, and thereby reduce the operation time, especially for the variation and size of the pressure required to complete the cold forming process. For this purpose, in the present paper a FE model will be established to simulate the Quickflange process by means of the commercial FE software Abaqus. The capability of the model will be investigated and discussed by comparing with experimental results.

2. Experimental work

In total, six fully instrumented Quickflange (6 in. diameter) connections were carried out. These are reported in this paper.

During the connection tests, the parameters that were measured are described in Table 1 and their positions are illustrated in Fig. 2.

Sensor position applied for the flange is given in Fig. 2.

Experiments were conducted for pipes that were machined to minimize ovality (test 1 to 4) and non-machined (test 5 to 6). As can be seen from Fig. 3 the pressure-stroke data are quite similar for the two types of pipes. The difference between the two types of tests seen in the initial part of the curves in Fig. 3 (stroke 8–10 mm) is explained by the initial gap between outer surface of pipe and adjacent inner surface of flange. The gap is larger for the machined pipes introducing plastic deformation as seen in the flat portion of the curve at about 8–10 mm of the pipe before it comes into contact with the flange. This is not the case for the non-machined pipes where there is a tight fit from the start between pipe and flange.