Effect of Incomplete Threads on the Jump-Out Tensile Failure of Premium Connections for Oil or Gas Wells*

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In order to develop deep wells in corrosive conditions, premium connections with high tensile strength and sealing performance are necessary. As for the high tensile strength, jump-out tensile failure, by which the tensile strength and the elongation of connections are decreased, should be prevented. The mechanical behavior and preventive conditions of the jump-out tensile failure are investigated through the failure analysis of connections with varied box-end profiles and thread length. Incomplete pin threads are necessary to prevent the jump-out tensile failure, in addition to the negative load flank angle thread for maintaining the engagement of the threads and the incomplete thread length for ensuring the shearing resistance. The rigidity of the box-end increased by a longer incomplete thread length and an unthreaded ring added to a box-end can help prevent the jump-out tensile failure by decreasing the deformation of the threads and the expansion of the box.

Key Words: Fixing Element, Ductile Fracture, Fracture Criterion, Connection, Thread, Strength, Jump-Out

1. Introduction

Recently, oil or gas producing wells have become deeper and more corrosive, thus increasing the severity of the operating conditions. In order to complete such deep and corrosive wells in safety, premium connections with high tensile strength and sealing performance are required⁽¹⁾⁽²⁾.

For the tensile strength, the jump-out tensile failure of the connection⁽³⁾⁽⁴⁾, that is a pulling-apart phenomenon of the internal threaded part (pin) from the external threaded part (box), should be prevented so as to achieve a high tensile loading capacity of the connection. Although the experimental tensile strength formulas of connections are presented in the API standard⁽⁵⁾, there have been few systematic investigations on the jump-out failure. The tensile failure mode of the connection for casing and tubing is different from that of the bolt⁽⁶⁾, because the thread

overlap of the connection is decreased by the radial shrinkage of the pipe due to the axial tension. Therefore, the load distribution at the threads analyzed on the bolt^{(7)~(9)} and the hollow-bolt⁽¹⁰⁾ does not always lead to the jump-out failure analysis of the connection.

In the last paper⁽²⁾, the effect of the thread profile and thread length on the jump-out failure mode of the connection was investigated by the tensile tests of the connections. As for the conditions used to prevent the jump-out failure, it was reported that the negative pressure flank angle and the incomplete thread length as well as the complete thread length are required.

In this paper, the jump-out failure mechanism and the preventive conditions were investigated by more detailed tensile strength tests while varying the incomplete thread length.

2. Connection Configuration

For the tapered pipe thread with a nominal diameter larger than 4 1/2" (114 mm), the buttress thread defined in the API standard⁽¹¹⁾ has been used. The parameters of the API buttress thread shown in Fig. 1 - (1) are the pitch $P=5.08$ mm, the thread height $H=$

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from the first engaged thread of the pin, as shown by point A in Fig. 2. The lengths L_a from the pin incomplete thread starting point B in Fig. 2 to the pin breakage point are listed in Table 2. With an increase in the length L_0 , the failure load and elongation increased slightly, but the failure mode did not change from the pin breakage.

In the case of $L_B=21.7$ mm and $L_0=0$ mm, the length L_a was 18.6 mm; that is, the pin broke at the threaded portion which was about 5 mm ($18.6-10.8-3$) near the pin tip. When the overhang portion was added to the box-end, that is, in the case of $L_B=21.7$ mm and $L_0=10.8$ mm, the failure mode changed to the pipe body breakage.

In the case of $L_B=32.5$ mm and $L_0=0$ mm, the pin broke at the threaded portion. Its failure load was smaller than that in the case of $L_B=21.7$ mm and $L_0=10.8$ mm with the same length of (L_B+L_0) . This result shows that the unthreaded overhang at the box-end increased the tensile strength of the connection.

Figure 3 shows the deformation of the pin inside diameter and the box outside diameter after failure in the typical failure modes. The result of $L_B=0$ mm and $L_0=32.5$ mm in Fig. 3-(1) shows that the sheared failure of threads occurred with the thread engagement due to the small pipe body radial shrinkage. In the case of $L_B=32.5$ mm and $L_0=0$ mm in Fig. 3-(3), the pin broke at the threaded portion of 17.5 mm near the pin tip, away from point B in Fig. 2, with loosening of the thread overlap at the box-end. In this case, the radial shrinkage of the pin incomplete thread was larger than that of the pipe body, because the pin incomplete thread is compressed in the radial direc-

Table 2 Test results of connections for API wall thickness pipe

A		Failure mode		<div>○ : Breakage in pipe body</div> <div>● : Jump out</div>			
B		Failure load($\times 10^3$ N)					
C		Elongation of pipe body (%)					
L_P/t	4.0	A	● ⁽³⁾	●	○	○	
		B	1284	1303	1372	1374	
		C	5.0	5.1	7.7	7.9	
	3.5	A	●	●	○	○	
		B	1274	1284	1362	1368	
		C	4.8	4.8	7.6	7.6	
	3.0	A	●		○ ⁽²⁾	○	
		B	1284		1352	1370	
		C	4.5		7.4	7.7	
	2.5	A	●		●	○ ⁽¹⁾	
		B	1127		1313	1368	
		C	3.0		5.5	7.6	
L_1 (mm)		0	13.2	26.4	51.2		
Taper			1/5.5		3/32		

(1)~(3) : corresponding to Fig. 4
1N=0.102kgf

tion by the box thread with loosening of the thread overlap. On the other hand, the result of $L_B=21.7$ mm and $L_0=10.8$ mm in Fig. 3-(2) shows that the pipe body broke with a larger radial shrinkage than that of the threaded portion, because the thread overlap was maintained by the small radial shrinkage of the pin caused by the small radial expansion of the box due to the rigidity of the box overhang L_0 .

3.2 Taper-threaded connection for heavy wall pipe

In the case of a heavy wall pipe, the higher tensile load is applied to the threads at the box-end. Because of the large deformation of the threads caused by the higher tensile load, the jump-out failure tends to occur. In ref. (2), the effect of the pressure flank angle and the thread length was investigated by tensile failure tests on the specimens with increased thread height in proportion to the pipe wall thickness. The parameters of the thread were: pitch, $P=6.35$ mm, thread height, $H=2.4$ mm, and thread taper, 1/16. The outside diameter of the pipe was $D=84.1$ mm, the pipe wall thickness was $t=14.3$ mm and the outside diameter of the box was 100 mm. From the test results

Fig. 3 Effect of the incomplete thread engagement conditions on the tensile failure mode

outlined in ref.(2), it was clarified that the jump-out failure could be prevented by a sufficiently long incomplete thread length as well as a complete thread length with a pressure flank angle smaller than -3 degrees. However, even when the jump-out failure did not occur, the slight radial expansion of the box-end leading to the decrease of the thread overlap was observed, as shown in Fig. 4-(2).

Therefore, in this section, in order to investigate the effect of increasing the incomplete thread length on the jump-out failure, tensile strength tests were conducted on the specimens whose incomplete thread length was increased from 26.4 mm to 51.2 mm by decreasing the thread taper from $1/5.5$ to $3/32$. The pressure flank angle of the specimen was -3 degrees. The mechanical properties of the material are shown in Table 1.

The test results are listed in Table 3 along with those obtained from the specimens with the -3 degree pressure flank angle thread reported in ref.(2). Breakage occurred in the pipe body when the complete thread length was 2.5 or more times the pipe wall thickness. The deformation of the pin inside diameter and the box outside diameter are shown in Fig. 4. As shown in Fig. 4-(1), a long incomplete thread length decreases the radial expansion of the box-end, which is effective for the prevention of the jump-out failure.

Fig. 4 Effect of the incomplete thread length on the tensile failure mode

When the incomplete thread length was increased by the small thread taper, maximum loading force was applied to the thread away from the box-end, which led to increasing the rigidity of the box-end and decreasing the radial expansion of the box-end.

The effects of the incomplete thread length on the failure load and the elongation of the pipe body at failure are summarized in Fig. 5. When the incomplete thread length is short, the jump-out failure could not be prevented by increasing the complete thread length, and the failure load and the elongation of the pipe body were smaller than those of the pipe body breakage. An incomplete thread length greater than or equal to 26.4 mm is required to prevent the jump-out failure. By increasing the incomplete thread length from 26.4 mm to 51.2 mm, the complete thread length necessary for the jump-out prevention was decreased due to the increased shearing resistance at the root of the long incomplete thread.

4. Considerations of the Mechanism of Jump-Out Failure

From the failure mode of the tensile tested specimens, it becomes clear that the jump-out failure occurs when the engaged threads are separated from the box-end by the pin shrinkage and the box expansion caused by the tensile load, and when the shearing load at the root of the threads could not resist the tensile load.

Table 3 Test results of heavy wall pipe connections

A	Failure mode				
B	Failure load($\times 10^3$ N)				
C	Elongation of pipe body (%)				
D	Location of pin breakage L_a (mm)				

◎ : Breakage in pipe body
 ○ : Breakage in pin thread
 ● : Jump out

L_o (mm)	32.5	A	● ⁽¹⁾				
		B	699				
		C	4.9				
		D	—				
	21.7	A	●	○			
		B	690	778			
		C	4.6	7.4			
		D	—	24.7			
	10.8	A	●	○	◎ ⁽²⁾		
		B	687	775	795		
		C	4.5	7.3	10.8		
		D	—	24.7	—		
	0	A	●	○	○	○ ⁽³⁾	
		B	682	770	774	775	
		C	4.3	6.9	7.2	7.3	
		D	—	25.0	18.6	17.5	
L_B (mm)		0	10.8	21.7	32.5		

(1)~(3) : corresponding to Fig. 3
 $1N=0.102\text{kgf}$

Table 4 shows the considerations of the mechanism of the jump-out failure. As shown in Fig. 6, the cross section of the first engaged pin thread root tends to yield before the pipe body, because the nominal axial stress σ_z^p at the pin thread root area S_{p1} is larger than the axial stress σ_z of the pipe body. In particular, in the case of a thread with a large positive pressure flank angle α , the circumferential constraint on the first engaged pin thread is decreased by the sliding-out of the threads, so the main stress component at the pin thread root cross section becomes the axial stress σ_z^p . Therefore, the pin shrinkage at the first engaged pin thread root where the first yielding occurs becomes larger than that of the pipe body. On the other hand, the box is expanded by the pin thread deformation. With an increase of the axial tension, the thread overlap decreases to zero due to the pin shrinkage and the box expansion, and the load which was carried by that sliding-out thread is redistributed to the remaining contacting threads. At this stage, the axial stress σ_z^p on the cross-sectional area S_{p2} of the first engaged pin thread root becomes larger than σ_z^p on S_{p1} due to the smaller area S_{p2} than S_{p1} caused by the thread taper. Therefore, the thread sliding-out phenomenon propagates to the pin tip thread, decreasing the engaged thread length. Finally, when the shearing

Fig. 5 Effect of the incomplete thread length on the tensile failure load and elongation of pipe body

strength at the root of the remaining engaged thread becomes smaller than the tensile strength of the pipe body, the pin jumps out from the box with the shearing of the threads.

In the case of the large negative pressure flank angle thread, as shown in Fig. 7, the load F acting on the pressure flank of the pin thread decreases the shrinkage of the pin, and the load F' on the box thread decreases the expansion of the box. The load F constrains the pin shrinkage at the first engaged pin thread; then the tensile hoop stress σ_t^p of the pin is generated. In the biaxial tensile stress condition of σ_z^p and σ_t^p , the equivalent stress σ_{eq}^p at the cross section of the first engaged pin thread root becomes smaller than the axial stress σ_z^p of the pipe body. Therefore, the yielding of the cross section of the first engaged pin thread root becomes difficult. This leads to the tight

Table 4 Mechanism of the jump-out failure

Fig. 6 Deformation of the connection by the axial tension

Fig. 7 The load carried on the pressure flank of thread

engagement of the threads and the prevention of the jump-out failure.

In the case of a box with the overhang as shown in Fig. 6, the first engaged pin thread is located near the pin tip away from the box-end. So, the rigidity of the overhang constrains the expansion of the box caused by the first pin thread deformation, which leads to the small expansion and bending deformation of the box. As a result, the pin shrinkage and the pin equivalent stress σ_{eq}^p decrease due to the constraint of the pin by the box and the tensile hoop stress σ_t in the pin, which leads to the pipe body breakage, as shown in Fig. 3-(2).

From the above considerations, it is clarified that the tensile strength of the connection for the pipe should not be designed only by the shearing strength of the threads on which the design of the bolt's strength is conducted. That is, in order to prevent the jump-out failure with the sliding-out of the threads at the axial tension smaller than the specified tensile strength, it is important to determine the incomplete thread length and the box configuration as well as the thread profile and the shearing resistance at the root of the threads.

5. Conclusions

For the tensile strength of the connection for oil or gas wells under severe operating conditions, the mechanism and prevention of the jump-out failure with a smaller failure load and elongation of the pipe body were investigated by model tests to check the effect of the incomplete thread. The findings are summarized as follows.

(1) Jump-out failure occurs when the engaged threads are separated from the box-end by the pin shrinkage and the box expansion caused by the tensile load, and the shearing load at the root of threads cannot resist the tensile load.

(2) An incomplete thread is required to prevent the jump-out failure, as are a negative pressure flank angle thread and a complete thread length maintain-

ing the shearing resistance at the root of threads.

(3) A sufficiently long incomplete thread is required to decrease the pin and box deformations, because it increases the rigidity of the box-end by moving the position of the maximum axial load on threads to the pin tip.

(4) The unthreaded ring at the box-end without engagement of the pin thread is effective for prevention of the jump-out failure, because it prevents the decrease of the thread overlap due to the expansion of the box caused by the deformed pin thread.

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