Study on the Technology of Solid Expandable Tubular in Open-Hole Well

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Abstract

During the production and drilling of open hole wells, due to the uncertainty and complexity of the rock,The naked hole section is prone to accidents such as collapse of the shaft wall and leakage. In order to solve the above problems, this paper proposes the plugging technology of solid expandable tubualr(SET) in open-hole wells. Based on experimental data,this paper established a dynamic three-dimensional model which considers friction and contact. The author puts forward the applicability criterion of open hole and studies the sensitivity parameters of expansion cone. The research results show that when SET specifications are determined, the borehole size of the open hole well has a great influence on the contact pressure, residual stress, driving force and other factors after the SET is formed, and to a certain extent affects the subsequent service. In addition, the structural parameters of the expansion cone also have a great influence on the plastic forming of SET. The results of this paper provide guidelines and theoretical basis for the use of SET technology in open hole wells.

1 Introduction

With the continuous development of social science, various new energy sources are emerging. But for a long time, oil and natural gas are still the main energy sources of human society[1]. With the development of oil and gas to deeper layers, the number of deep wells, ultra-deep wells, complex structure wells and special craft wells is increasing[2]. Therefore, the stratum structure encountered during the drilling process is becoming more and more complex, and the difficulty of completion is increasing day by day. In complex strata which is high-pressure layers or lost layers, the traditional methods have little effect on the leakage and collapse accidents. However, the advantages of using SET technology to repair the local corrosion, perforation of the casing, and blocking the lost layer are obvious[3].

In the 1990s, SET technology gradually emerged. It is a technology that uses the cold plastic forming characteristics of metals and relies on external force to expand the inner diameter to the required value. After decades of development, it has achieved tremendous development in plugging, repairing casing, and optimizing the wellbore structure[4]. In recent years, a large number of scholars and engineers have conducted research on many aspects of the technologyThey mainly focused on the selection of materials, the optimization of the expansion cone, the collapse after expansion, the expansion force, etc., and achieved remarkable achievements[5–14]. In general, there are few studies on open hole wells, and these studies are mainly on casing damaged wells[15].

Due to the essential difference between open hole wells and casing wells, there are huge difference between the two in the process of applying SET. Although Halliburton, Weatherford and Baker Hughes and other companies have successfully applied some cases in Enventure,but due to the complexity of open hole wells,they still have broad research prospects.

In this paper, for the SET (152 mm × 8 mm) and 61/2 open-hole wells, it study the applicability criteria of the borehole and the influence of the expansion cone structure on the forming of SET. Based on experimental data,this paper established a dynamic three-dimensional model which considers friction and contact. This paper studies the influence of borehole size on the stress change and driving force during SET expansion.The influence of SET's residual stress and sealing capacity after expansion was also studied.In addition, the sensitive parameters of the expansion cone are analyzed.

2 Mechanical Uniaxial Tensile Test

This article selects 20G (foreign grades: Germany st45.8, Japan STB42, and US SA106B)and 316L stainless steel as the research object. Based on the national standard (GB/T 228.1–2010), a uniaxial tensile test was carried out to obtain the stress-strain curve of the material(see Fig. 1 for the sample). Since the forming process is essentially plastically deformed, the plastic section of the stress-strain is mainly used. The data obtained from the experiment is nominal and converted into engineering stress-engineering strain curve[16] (Fig. 2).

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3 Finite Element Analysis And Discussion

This paper established a 3D dynamic model considering friction and contact by CAE software. The model includes expansion cone, SET, rubber ring and open-hole well. Specifically:(1)Expansion cone: The expansion cone is defined as a rigid body, its maximum outer diameter is 154 mm (expansion rate is 13.2%), and the cone angle is 12°. Limit all degrees of freedom except for the Z direction, and only move along the Z axis (Fig. 3). (2)SET: SET is radially meshed into 4 layers; In order to ensure the consistency of the construction method, all degrees of freedom are limited at the end of the expansion of the pipe, so as to achieve complete fixation. (The right end of Fig. 3) In addition, the material parameters of the SET are set according to the data in Fig. 2. (3)Rubber ring: rubber ring is used The Mooney-Rivlin model is used to describe[12]. Three rubber rings are bound to the outer wall of SET. (4) open-hole well:the wellbore is designed according to the basic rock parameters and The wellbore specification is 6 1/2in (165 mm). The finite element model is shown in Fig. 3.

3.1 Applicability analysis of wellbore

The size of the wellbore determines the interference between the rubber ring and the rock. Too large or too small hole size will affect the forming and operation of SET. Therefore, it is of great significance to SET to find a suitable wellbore size. Without considering the thinning of the SET wall and the compression of the rubber ring,The outer diameter of SET after expansion is 168 mm, and the outer diameter of rubber ring is 184 mm. Through the above analysis, the size of the wellbore should vary from 168 to 184 mm. Combined with the compression of the rubber ring, paper selected 174 mm, 176 mm, 178 mm, 180 mm and 182 mm wellbore for research and analysis.

3.1.1 Effect of wellbore size on SET expansion

First, one of the keys to SET technology is the success of expansion. Therefore, it is very necessary to study the stress of the pipe during the expansion process[17]. As shown in Fig. 4, the residual stress of the two tubes after expansion decreases with the increase of the wellbore size. The residual stress value does not exceed the ultimate tensile strength (659 and 978 MPa). However, the stress value during expansion cannot be ignored. It can be seen from Fig. 5 that when the borehole size is 174 mm and 176 mm, the stress value of SET (20G) exceeds the tensile strength and has failed.In addition, the author also found that the safety factor of using 316L steel is higher than 20G.

From the law of residual stress and safety factor, the conclusion as shown in Table 1 can be obtained:

Table 1
Wellbore size range based on stress.

Wellbore size(mm)	174	176	178	180	182
20G	×	×	√	√	√
316L	√	√	√	√	√

3.1.2 Effect of wellbore size on expansion force

The expansion force is an important parameter of expansion deformation, and the magnitude of the expansion force will directly affect the quality of the expansion process. Before designing the expansion mechanism and formulating the expansion process, the size of the expansion force must be determined. It is one of the key factors that determine the success of the expansion operation [18].

It can be seen from Figs. 6 and 7 that under the same material condition, the expansion force in the presence of rubber is greater than that in the absence of rubber. The size of the wellbore directly determines the amount of interference of the rubber. During the expansion process, if the wellbore size is too small, the compression of the rubber ring is too large. Compared with the two materials, 316L steel is easier to expand than 20G.

The expansion force of SET should be as small and stable as possible when expanding. Combining Figs. 6 and 7, the conclusion as shown in Table 2 can be obtained.

Table 2
Wellbore size range based on expansion fprce.

Wellbore size(mm)	174	176	178	180	182
20G	×	×	√	√	√
316L	×	√	√	√	√

3.1.3 Effect of wellbore size on contact pressure

The sealing pressure is achieved after the rubber ring is compressed. While ensuring the pressure, the rubber ring is not crushed[19]. As can be seen from Fig. 8, the contact pressure of the rubber ring has nothing to do with the material of SET. It can also be seen that the smaller the wellbore size, the greater the residual stress and contact pressure of the rubber ring. Combining Fig. 8 (a) and (b) can get the conclusion of Table 3:

Table 3
Wellbore size range based on rubber ring.

Wellbore size(mm)	174	176	178	180	182
20G	×	√	√	√	×
316L	×	√	√	√	×

3.1.4 Open-hole applicability criteria

When the wellbore size is greater than 180 mm, SET operations of other specifications should be adopted. When the wellbore size is less than 176 mm, the wellbore size should be expanded to the range of 176 mm to 180 mm. Combined with the analysis results of SET's residual stress, expansion force, contact pressure and other parameters, the applicable wellbore size of 152 mm SET shown in Table 4. Through the study of the borehole applicability of the 6 1 / 2in open-hole well, it was converted into the compression amount of the rubber ring. Through calculation, when the material is 20G, the compression of the rubber ring is guaranteed to be 25–50%; when the material is 316L, the compression of the rubber ring is 12.5% -62.5%. Therefore, when designing the SET of open-hole wells, design can be made with reference to the amount of compression. This criterion is of great significance to the design of rubber ring in open-hole wells.

Table 4
Wellbore applicability criteria.`

Wellbore size	Down(>)	Up(<)	Theoretical compression of rubber ring
20G	176 mm	180 mm	25%-50%
316L	174 mm	182 mm	12.5%-62.5%

3.2 Analysis of sensitive parameters of expansion cone

Reasonable expansion cone structure parameters are more conducive to expansion forming. The optimization of the expansion cone is very necessary and has practical significance [11, 19]. The structure of the expansion cone has a significant impact on the expansion force of SET technology and the residual stress of the tube. Although many researchers have studied the expansion cone, it is found through investigation that SETs with different specifications often have different requirements for the expansion cone structure.

The expansion cone structure is divided into a guide area (Ⅰ area), an expansion area (Ⅱ area) and a diameter maintaining area (Ⅲ area) (Fig. 9 (a)). In the actual simulation process, the author found that the expansion cone was not well integrated with SET(Fig. 9(b)), and the sharp corner transition occurred. Therefore, the sharp angles of the A and B areas are optimized and analyzed.

3.2.1 Cone angle optimization of expansion cone

3.2.2 Optimization analysis of chamfering in area A

3.2.3 Optimization analysis of chamfering in area B

It can be seen from Fig. 13 that as the chamfering of the area B gradually increases, the SET molding effect is better. It can be seen that with the increase of the chamfer size, the uniformity of the inner wall of SET increases, and the protrusion at the position of the rubber ring becomes gentle, which makes the pipe material have better mechanical properties after expansion.In addition, it can also be seen that when the chamfer size is smaller, the inner diameter of the tube shows an increasing trend after expansion,From another aspect, it is also confirmed that the expansion cone has a greater influence on the plastic forming and plastic flow of SET.

3.2.4 Summary

Through a lot of simulation analysis, it is found that the expansion cone angle and chamfering parameters have an important influence on SET forming, and also have a greater *influence* on SET plastic flow. In addition, the research results can increase the success rate of inflation and reduce the risk. The specific data after optimization is in the Table 5:

Table 5
Parameters after optimization of expansion cone.

	parameter
Cone angle(°)	8 ~ 10
Chamfering in area A(mm)	50 ~ 100
Chamfering in area B(mm)	100 ~ 200

4 Conclusions

In this paper, borehole applicability research and optimization of sensitive parameters after expansion were conducted for 152mmSET and 61 / 2in open hole. Due to the uncertainty of the rock, it is difficult to carry out the experiment, but it can be simulated by numerical simulation. The research results have a guiding effect on the open hole SET technology. Based on the research content of this article, the following conclusions are drawn:

1. 1.20G and 316L steel have good plastic forming characteristics, suitable for development as the base material of the expansion tube. Since 316L has better corrosion and toughness characteristics than 20G, it is recommended that it can be applied to areas with strong corrosion and areas with difficult expansion.
2. 2. Open-hole wells have the characteristics of irregular boreholes and large differences in rock properties. When SET is performed on open-hole wells, accurate and rigorous logging should be performed to determine the detailed size of the borehole. Combined with the research results, the amount of compression of the rubber ring outside the SET will have a greater impact on the tubing. So it is very necessary to put forward the criteria for the suitability of the open hole and select the standard specifications according to the criteria to improve the success rate.
3. 3. The expansion cone parameters will have a huge impact on SET forming. Combined with the research results, the design of the expansion cone should not only consider the effect of the cone angle, but also consider the transition problem of the contact section, which can greatly reduce the residual stress and expansion force of the tube after expansion.

The research results of this paper have a strong theoretical guiding significance for the construction and design of SET technology in open hole wells. The proposed wellbore applicability criteria will greatly avoid accidents and provide theory for the development of SET technology.

Availability of data and materials

The datasets used or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Availability of data and materials

The datasets used or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors have declared that no competing interests exist.

Funding

Not applicable

Authors' contributions

Dr. Xiaohua Zhu provided ideas and framework for the article; Feilong Cheng wrote the article and data processing; Changshuai Shi and Kailin Chen modified the article and helped with data processing together, the establishment of the finite element model.

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Figures

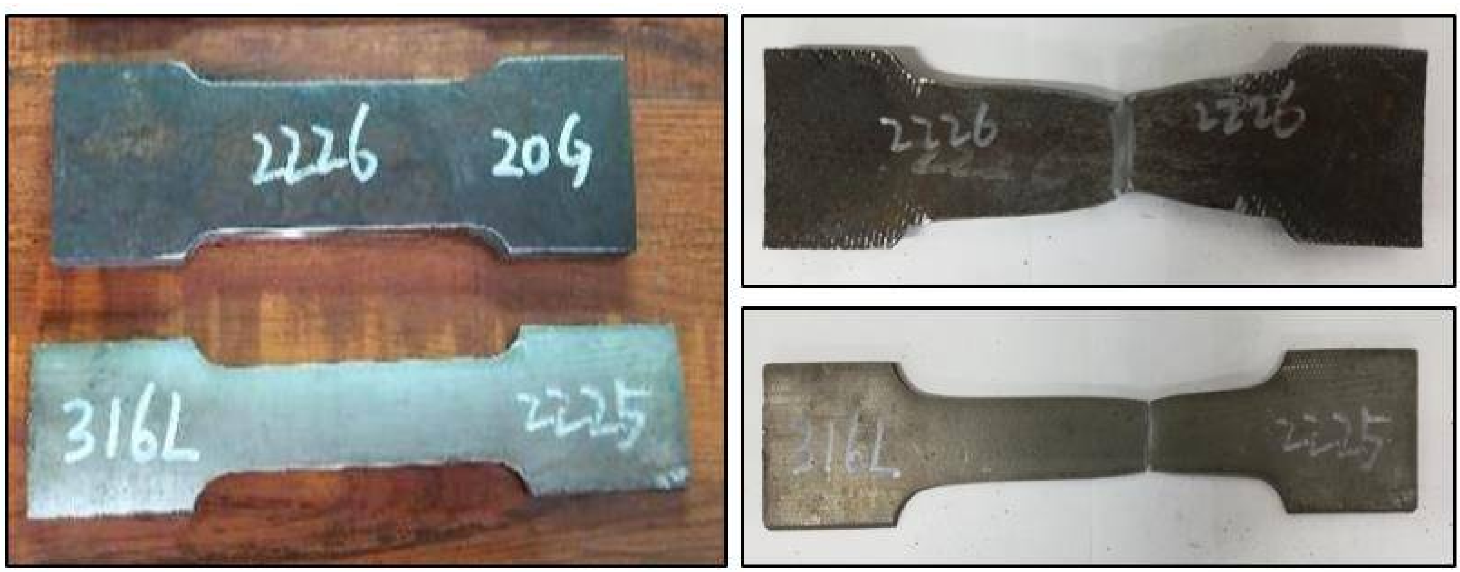

Figure 1

Structure of sample before and after experiment

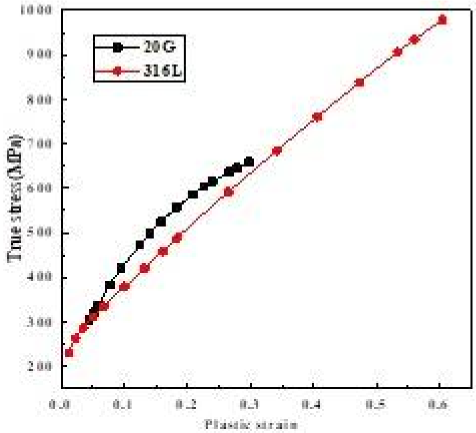

Figure 2

The converted stress-strain curve

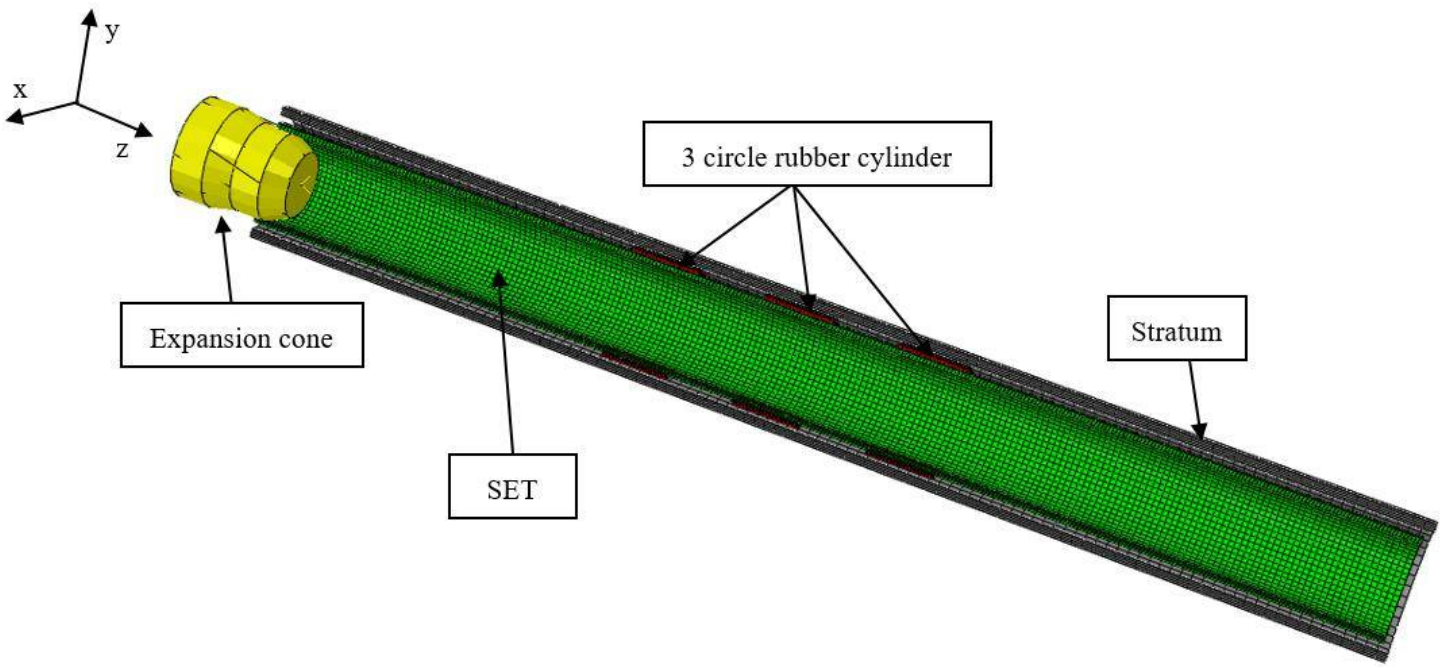

Figure 3

FEM

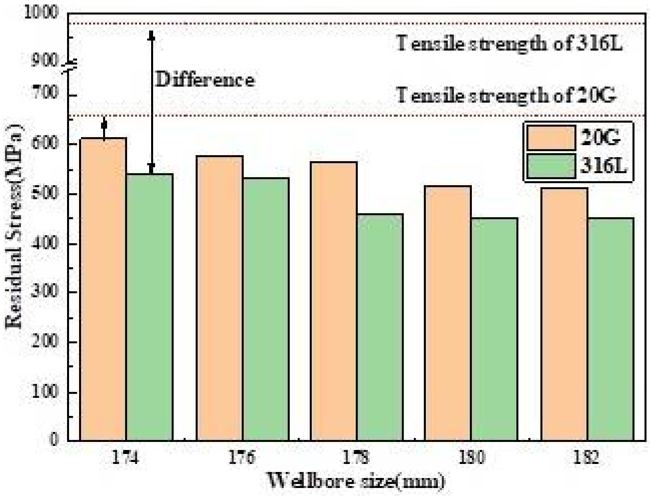

Figure 4

Influenced by wellbore size on residual stress

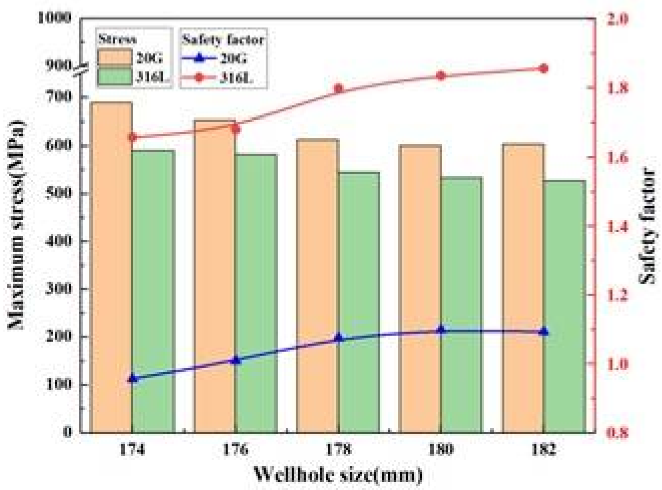

Figure 5

Influence of wellbore size on maximum stress during expansion

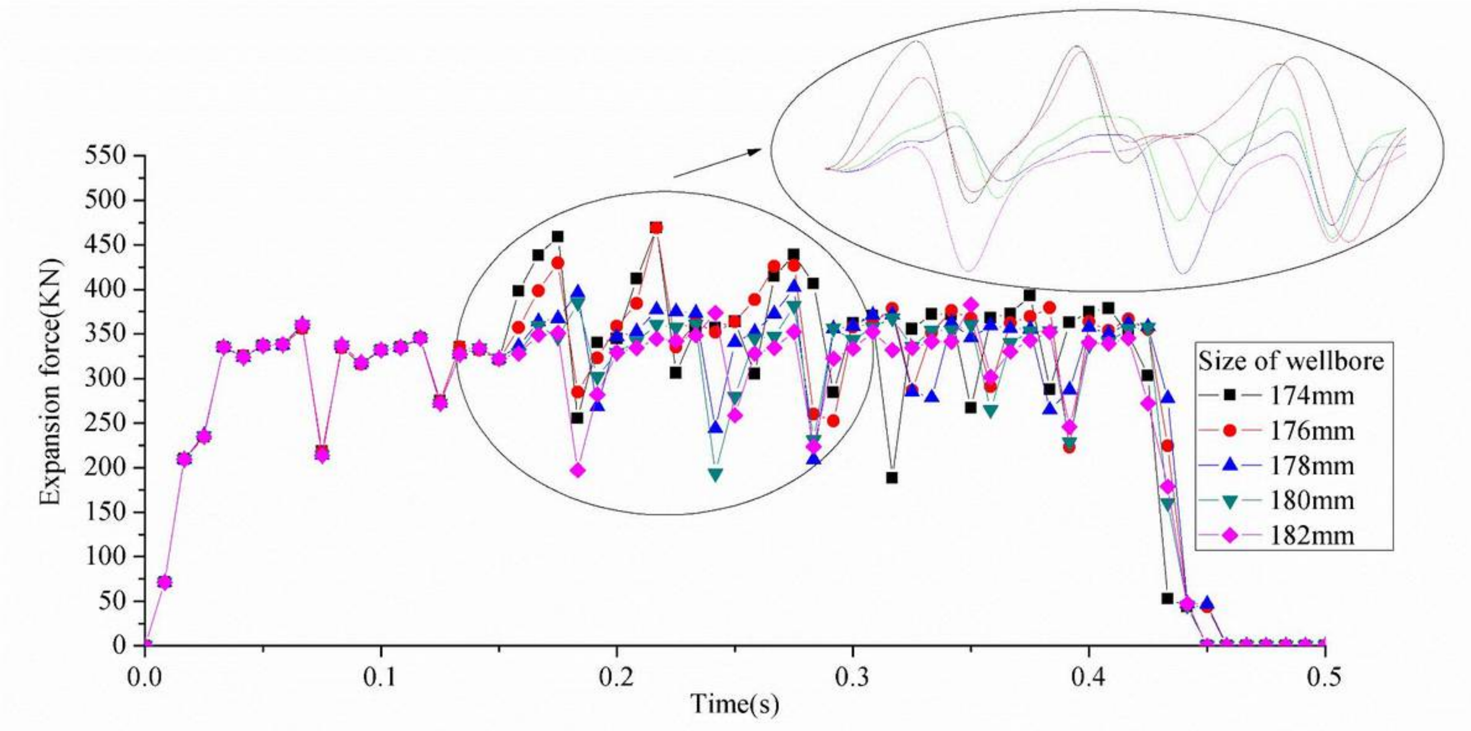

Figure 6

Influence of wellbore size on driving force at 20G

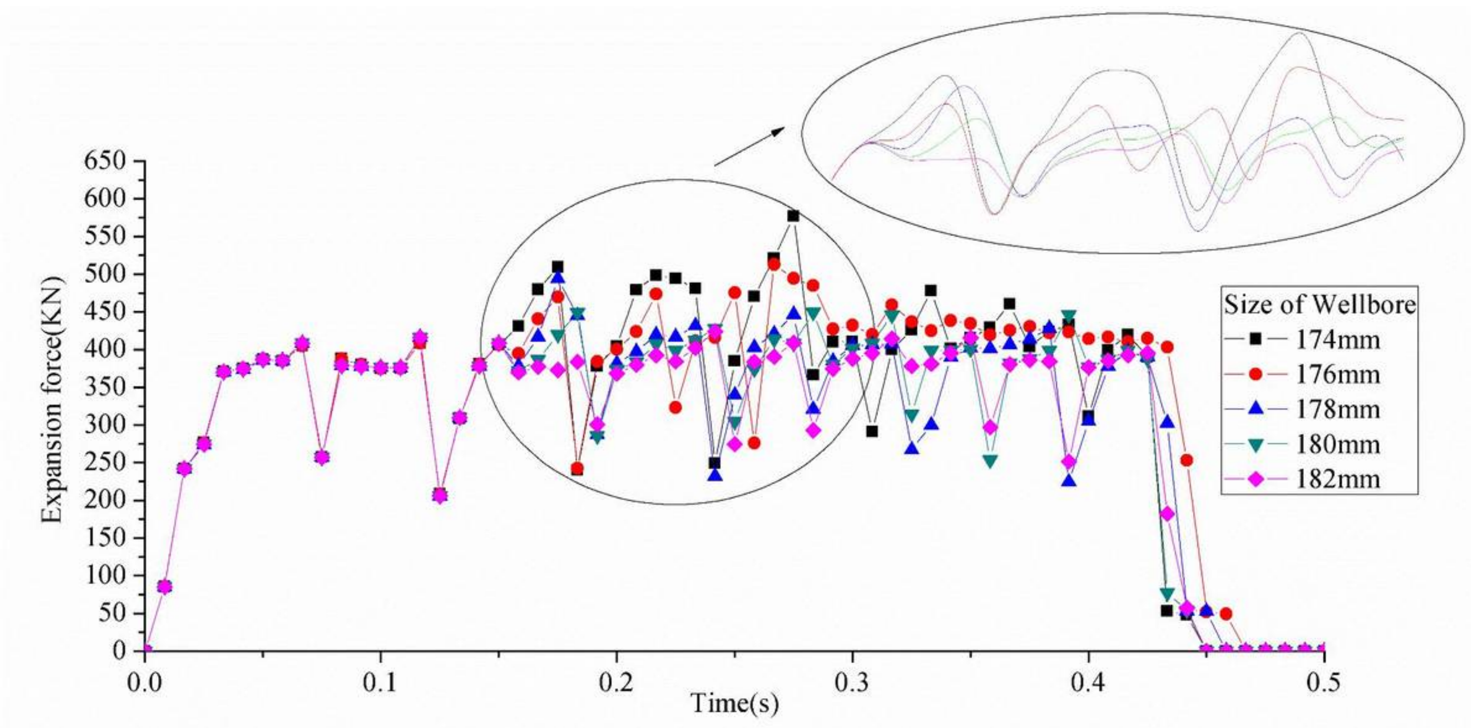

Figure 7

Influence of wellbore size on driving force at 316L

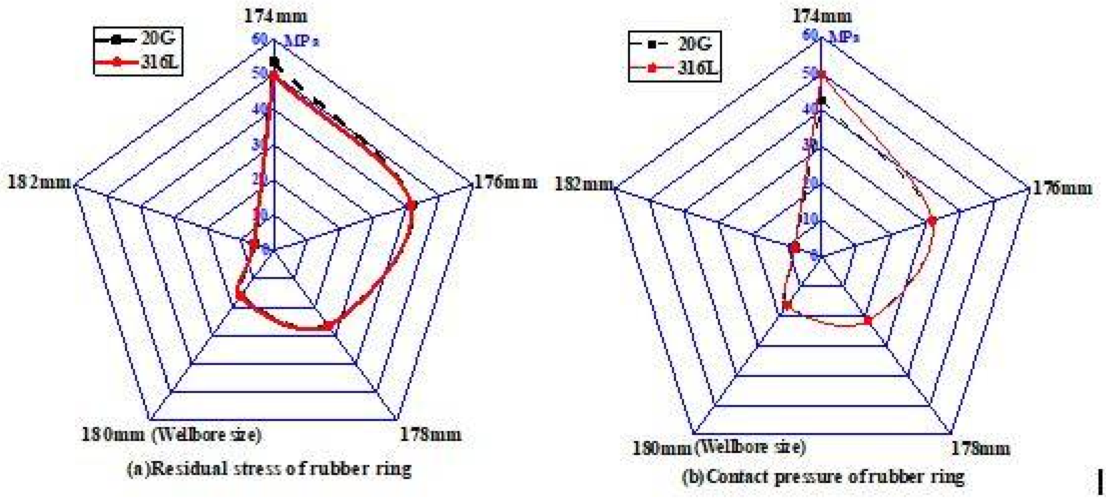

Figure 8

Influence of wellbore size on rubber ring

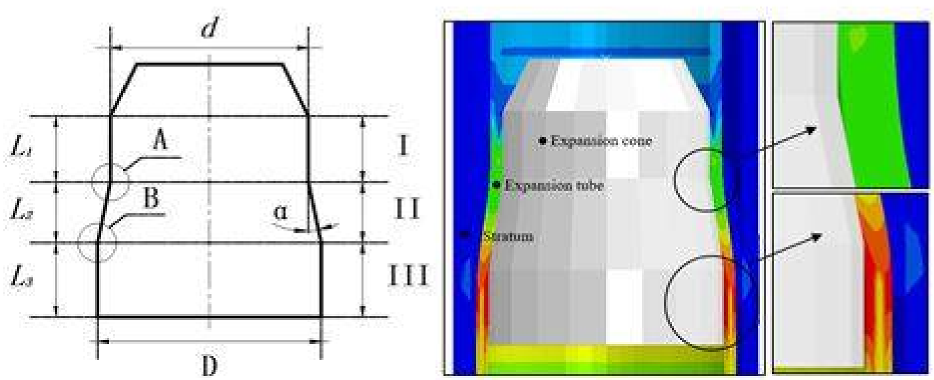

Figure 9

Schematic diagram of the structure and contact of the expansion cone

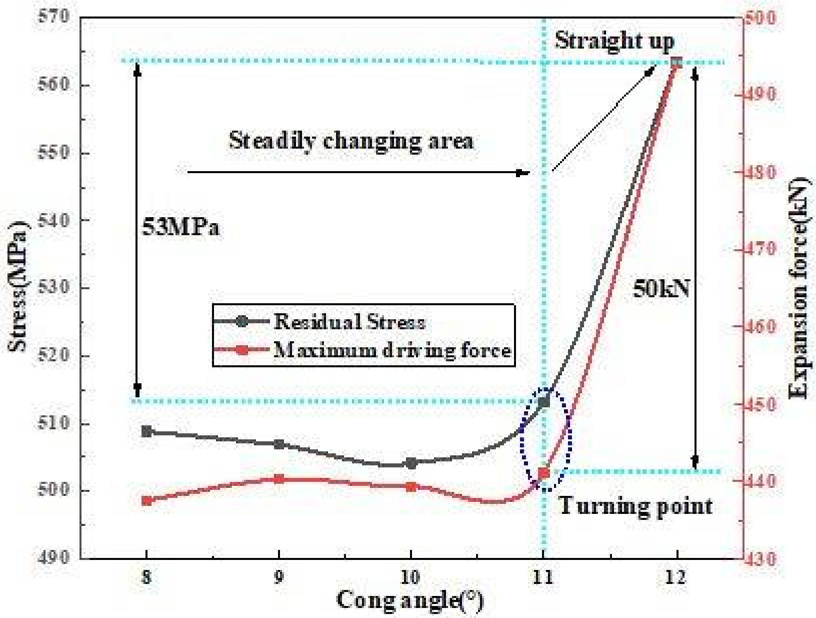

Figure 10

The effect of cone angle on forming

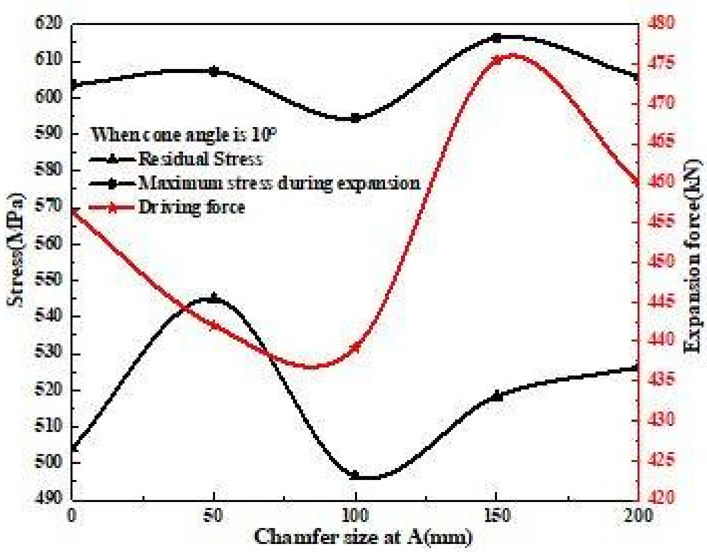

Figure 11

The effect of chamfering in area A on forming

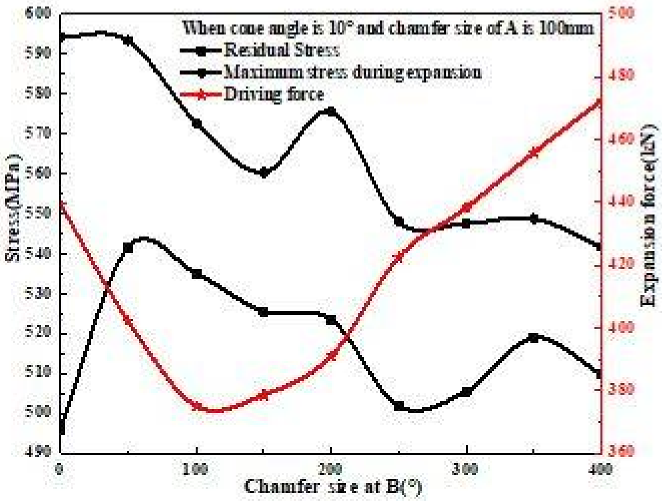

Figure 12

The effect of chamfering in area B on forming

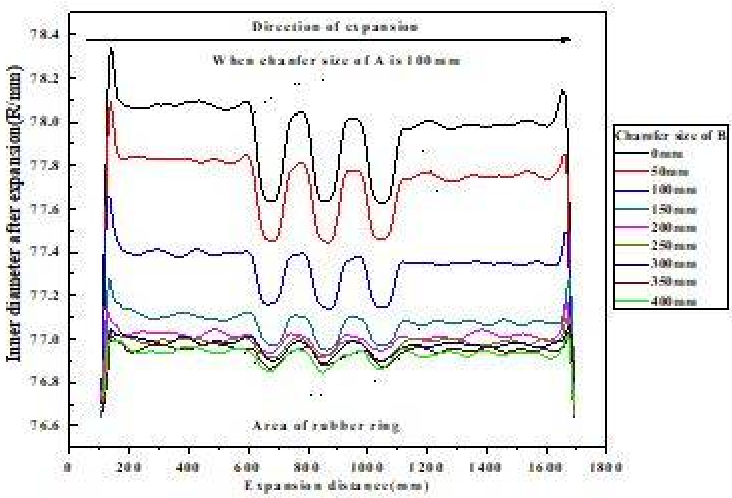

Figure 13

The influence of chamfering in B area on the inner diameter of SET after expansion