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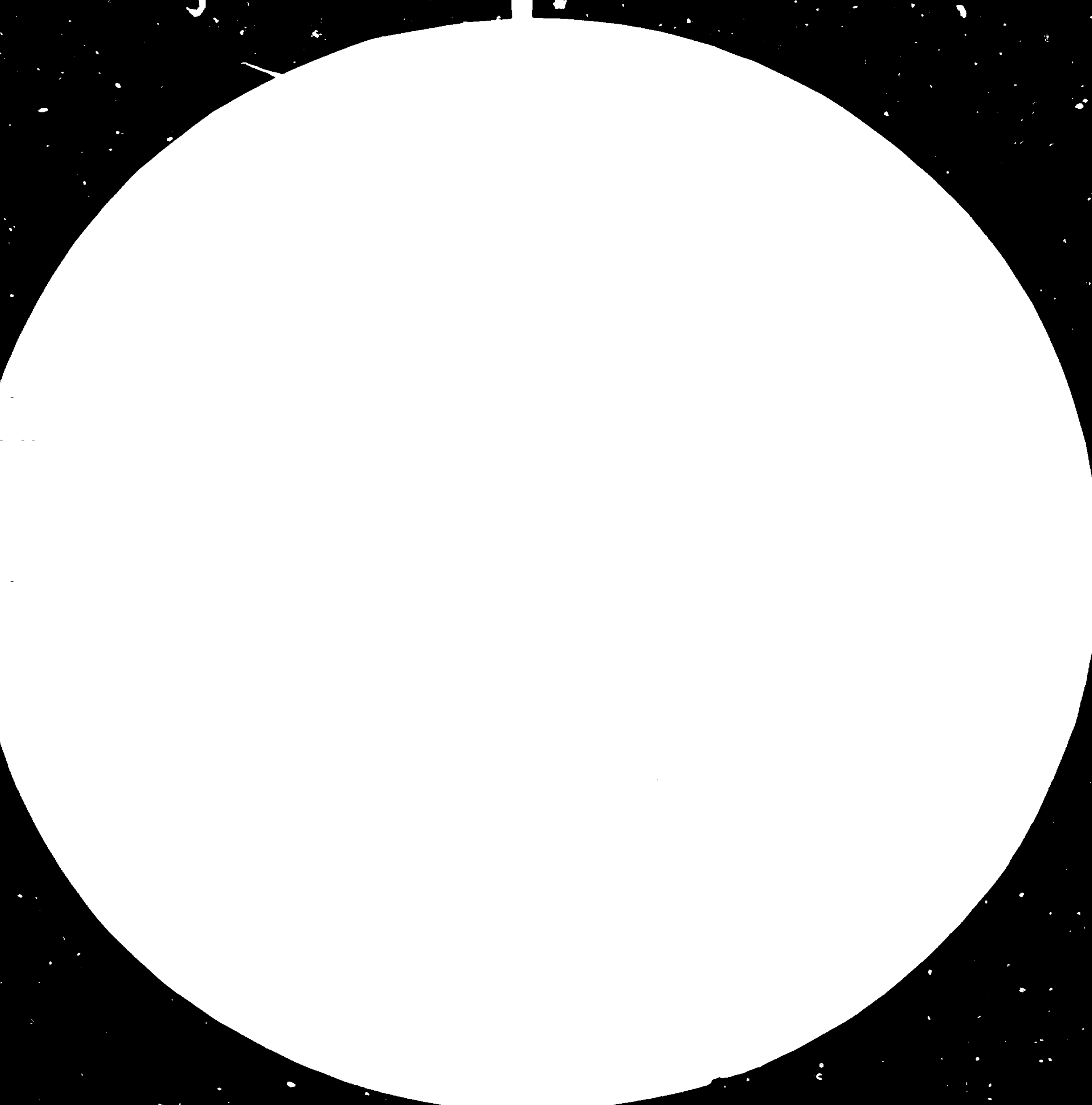

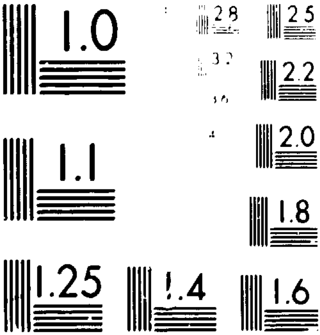
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Distr.
LIMITED

ID/WG.364/15
24 May 1982

ENGLISH

United Nations Industrial Development Organization

Technical Conference on Ammonia Fertilizer Technology for Promotion of Economic Co-operation among Developing Countries

Beijing, People's Republic of China, 13 - 28 March 1982

THE MANUFACTURE OF HIGH PRESURRE VESSELS FOR NITROGENOUS FERTILIZER PLANT *

by

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V.82-26533

ABSTRACT

In 1958, China began massive production of complete set of equipment for nitrogenous fertilizer plant. Since then more than 30 synthetic ammonia plants each with a capacity of 200 tons per day have been put into operation.

For high-pressure vessels, there are 4 types of structure that are most widely used today, they are shrink fit structure, welded mono-wall structure, multi-layer bundle-up structure and steel strip spiral winding structure (it means that the core cylinder is wound with a steel strip at an inclined angle in a criss-cross manner). With these types of structure, we have made quite a number of large vessels, and all these vessels are in operation. Now we have accumulated rich experiences in design, fabrication and operation of high pressure vessels through 20 years of practice.

All high pressure vessel manufacturers in China are equipped with relatively complete machinery and have a relatively sound technical force. In addition, we are carrying out a set of stringent quality control systems to ensure the quality of the products and safety in operation.

1. A general view to the manufacture of complete set of nitrogenous fertilizer plant and high pressure vessels in China.

In 1958, we began to design and manufacture complete set of nitrogenous fertilizer plant with various sizes by ourselves. From that time on we have put into operation, for example, more than 30 sets of ammonia plant, each with a capacity of 200 tons per day.

As I mentioned before, we have designed and manufactured the principal equipment for nitrogenous fertilizer plant, such as furnaces, waste heat boilers, towers, high pressure vessels, gas compressors, pumps, refrigerators, air-separation equipment, nitrogen scrubbers, valves, pipes, etc..

High pressure vessel is one of the key equipment in nitrogenous fertilizer production. Good quality of the equipment ensures not only the smooth running of the plant, but also the elimination of disastrous accidents.

For nearly 25 years, we have accumulated rich experiences in fabricating high pressure vessels after the first multi-layer bundle up high pressure vessel with an internal diameter of 800 mm was successfully manufactured in 1956, We are now able to manufacture various types of high pressure vessels, of which multi-layer bundle up structure, multi-layer shrink fit structure and welded mono-wall structure are most commonly used for fabricating medium and large size high pressure vessels. Till now, we have successively constructed quite a number of relatively large vessels and put them into operation, such as two-layer shrink fit ammonia converter of Ø 1600 mm three-layer shrink fit ammonia converter of Ø 3200 mm weighing 300 tons, and welded mono-wqll urea reactor of Ø 2100 mm, lined with 316L stainless steel, etc., At present, there are many pressure vessel manufacturers in our country, who are capable of fabricating welded mono-wall vessels with wall thickness less than 115 mm; multi-layer bundle up vessels with diameter less than Ø 3500 mm and multi-layer shrink fit vessels with a total weight not more than 400 tons.

Low alloy steels with yield limit within the range of 35-50 kgf/mm^2 are most common materials for making high pressure vessels.

Our manufacturers can undertake the fabrication and inspection of high pressure vessels according to any country's, regulations, standards, procedures or even any special requirements raised by customers.

11. The manufacture of high pressure vessels for nitrogenous fertilizer plant

In this paper, I would mainly and briefly introduce the present fabrication status of the 4 types of structure of high pressure vessels as I have mentioned before, i.e. multi-layer shrink fit structure, welded mono-wall structure, multi-layer bundle up structure and steel strip spiral winding structure (the vessel is formed by winding a steel strip onto the core cylinder at an inclined angle and in a criss-cross manner) and the linings for these vessels.

A. The manufacture of multi-layer shrink fit vessels

1. General description

Shrinkage fitting vessels are characterized not only by safety in operation, reliability of materials and flexibility in design, which are the main features of multi-layer assembled vessels, but also by short manufacture cycle, high productivity, which are known as major features of mono-wall vessels. This kind of structure has become a major structure of large and medium size high pressure vessels in our country.

We have made a systematic study by testing of shrink fit vessels with and without machined contact surface, (including hooped vessels without prewelding of the annular seams on the outer shell). For instance, the elimination of excessive stress, excessive stress distribution and burst test. Based on the data obtained from the tests, we have established "The Technical Regulations for Shrink Fit Pressure Vessels" and main manufacturing technology. We have constructed about 10 two-layer or three-layer shrink fit vessels, with internal diameters from Ø 900 - Ø 3200 mm and working pressure from 150-320 kgf/cm^2, and the maximum thickness of wall 162 mm. These vessels are running now.

Because the excessive stress has been relieved by heat treatment, the shrink fit residual stress is relatively at a low level. The stress distribution of the vessel is similar to the mono-wall vessels under pressurized conditions. So it is quite safe if the design shrink fit vessel is considered as a usual mono-wall vessel.

2. Manufacturing technology

In order to ensure product quality, the following must be controlled and inspected:

(1). The steel plate must be subjected to 100% ultrasonic inspection and the surface of the plate should be good. The thickness deviation of the plates used for constructing the same unit cylinder should be kept below 0.5 mm.

(2). After longitudinal welding, the weld on both sides should be ground on so as to make the welding area have a smooth transition to the adjacent area of the cylinder.

(3). It is necessary to apply first anti-cracking welding on the grooves of the circumferential welds before actual welding begins, in order to prevent the occurence of cracking or slag inclusion in the clearance during the circumferential welding and to convenience the ultrasonic inspection on the welds of the multi-layer cylinder to precisely reflect the welding quality. The circumferential welds and the type of anti-cracking welding grooves are shown in Fig. 1 and 2 as an illustration.

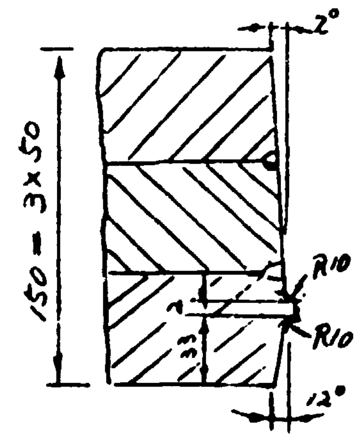

Fig.1.Unit cylinder and its circumferential weld groove

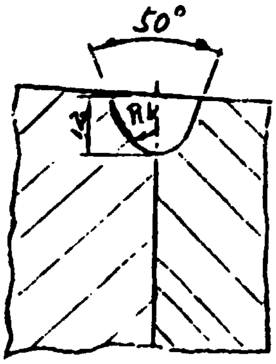

Fig.2. Anti-crack weld groove

(4). The longitudinal welds on each layer and all circumferential welds (including anti-crack welding seams) should be subjected to 100% radioactive ray or ultrasonic and magnetic inspection.

(5). Hydrostatic test

B. The manufacture of mono-layer vessels

The process for fabricating welded mono-layer vessels is just the same with that of unit cylinder of multi-layer shrink fit vessels. The only difference is that the steel plate used for manufacturing mono-layer vessels is much thicker. Therefore it is of considerable importance, during heat treatment, to control the quenching degree.

C. The manufacture of multi-layer bundle-up vessels

1. General

Multi-layer bundle-up structure is the earliest type of structure adopted in high pressure vessel manufacture activities in our country. The main features of this kind of structure are safe operation, homogeneous materials, reliable properties and easy fabrication. Currently it is a still principal structure of our high pressure vessels in ammonia plant.

In fabricating multi-layer bundle-up high pressure vessels, the first thing is the proper control of bundling up prestress, the clearance between layers, and the welding quality.

We have selected two multi-layer bundle-up unit cylinders fabricated according to the established technical regulations for actual measurement of the bundle up prestress. One cylinder is:

design pressure: 320 kgf/cm^2
inside diameter: Ø 800 mm,
total thickness: 79 mm,
lenth of unit cylinder: 1800 mm,
inner shell thickness: 25 mm,
bundle up plate thickness: 6 mm,
number of layers: 9;

The other is:

design pressure: 160 kgf/cm^2,
inside diameter: Ø 2100 mm,
total thickness: 108 mm,
lenth of unit cylinder: 1800 mm,
inner shell thickness: 24 mm,
bundle up plate thickness: 12 mm,
number of layers: 7.

Based on the test, it may be summarizied as follows;

(1). The tangential bundling-up prestress is caused mainly by the transverse shrinkage of the longitudinal weldings of the layer plate.

(2). The tangential prestress of the inner shell caused by the transverse shrinkage of the longitudinal weldings of the layer plate is unevenly distributed as shown in Fig. 3. Because the longitudinal weld of all layers are displaced with one another in a gradient way, the prestrees caused by the shrinkage of longitudinal weld is on the whole uniform after bundling up many layers.

(3). There is no direct correlation between the looseness of the bundling and the bundle up prestress. The most important factors that influence the looseness of the bundling are the evenness and surface properties of the plate.

(4). After bundling up the layers of the two unit cylinders, the annular prestress on is caused the inside walls of th inner shells.
The existence of these prestresses are helpful to improve the load on the inside wall of the vessels.

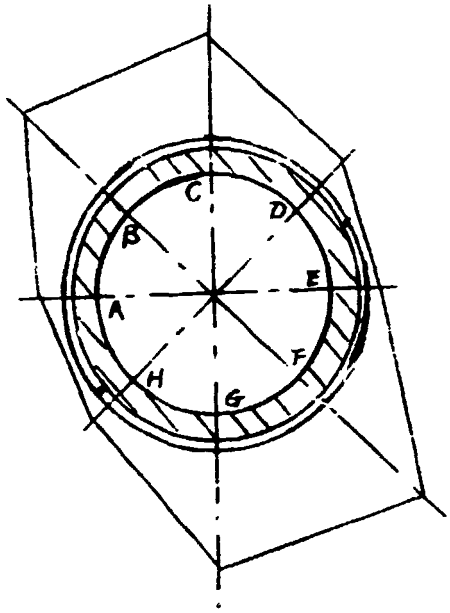

Fig.3 The tangential prestress of the inner shell caused by the shrinkage of longitudinal weldings of the layer plate.

Over 6 multi-layer bundle up vessels have been burst in our high pressure vessel manufacturers, as shown in Table 1. From the Table, it is readily seen that the quality of the vessels can satisfactorily meet the design requirements. At present, our biggest machine can bundle up vessels with diameters from Ø 500-3500 mm, and layer plate thickness from 6-12 mm.

2. The manufacture of inner shell

The inner shell of multi-layer vessels (including various structures of inner shells) serves not only to withstand the internal pressure, but also encloses the medium of the vessel. Although the inner shell of multi-layer vessel is relatively thin (usually from 10-25 mm), the fabrication of it should be under extremely stringent control, for exampe:

The inner shell plate should be subjected to 100% ultrasonic inspection. The surface should be clean and even.

The ellipticity of the unit cylinder should not be more than 0.5%.

The longitudinal seams after welding should be heat-treated to relieve the weld residual stress. All longitudinal seams should be subjected to 100% radioactive rays or ultrasonic and magnetic particle inspection.

Table 1 Burst Test of Multi-layer Bundle-up High Pressure Vessels

serial No.	inside diameter mm	wall thickness mm	diameter ratio K	inner shell		layer plate		bursting pressure calculated from medium diameter formula kgf/cm²	actual bursting pressure kgf/cm²
				material	thickness mm	material	thickness mm		
1	584	112	1.38	20_g	13	A_3R	4.5 6.0	1375	1265
2	800	169	1.422	20_g	13	20_g	6	1660	1705
3	600	97	1.323	st.52 (W.G.)	13	st.52 (W.G.)	6	1540	1550
4	420	85	1.40	20_g	13	A_3R	6	1505	1575
5	800	52.5	1.13	14MnMoVB	22	14MnMoVB	6	910	955
6	800	48	1.12	15MnV	12	14MnMoNbB	6	855	869

3. The bundling up of the layers, the butt joining and welding of the unit cylinders

The plate for fabricating layers should be carefully selected.

The drawing force of oil cylider should be correctly selected to match the thickness and mechanical properties of the plate. Necessary measures should be taken to make the layers contact with each other as tight as possible.

For inner shells with $\delta/R<5\%$ (δ represents inner shell thickness; R, inside radius of the unit cylinder), padding devices for supporting inner shell should be applied before bundling up. After having bundled up one layer, a check should be carried out to detect the loose area.

When the yield limit of the inner shell material is $\sigma_s \geq 50$ kgf/mm^2 , the welds should be reinspected with magnetic particle and ultrasonic after hydrostatic test.

4. The dislocation structure of circumferential welds

Generally the dislocation structure shown in Fig. 4 can avoid the deep welding of the circumferential welds for multi-layer bundle-up vessels, thus reducing the welding defects and raising the quality as well as safety of the multi-layer bundle up vessels.

Considering structural rationality of the dislocation and effects exerted by the contraction of the circumferential welds on the tightness of contact between layers, it is advisable, based on tests, to take L= 50 mm, L_1=30-50 mm, and α=30°.

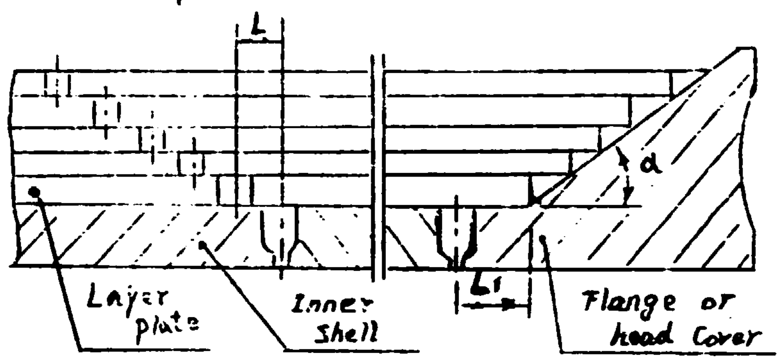

Fig.4. The multi-layer bundle-up vessel with dislocation of circumferential weld

(D) The manufacture of steel strip winding high pressure vessels

In 1965, we developed the spiral structure high pressure vessels which are fabricated by winding steel strips onto a core cylinder at an inclined angle in a criss-cross manner. This type of structure is characterized with following features: simple fabrication, safe operation, high productivity and low cost. We have fabricated over 1500 vessels of this type since then with inside diameters from Ø 450-1000 mm, design pressure from 150-320 kgf/cm^2.

The structure of steel strip winding vessels is shown in Fig. 5.

Because the adjacent strip layers are wound in an opposite direction, the core cylinder will not be affected by torsional and shearing stresses. The relatively large inclination angle overcomes the insufficient axial tensile strength, a weak point accompanied to the spiral vessels fabricated by fitting-up section steel. In addition, equal annular and axial tensile strength design can be realized through the adjustment of the inclination angle when winding the steel strip.

At present, we usually use small dimension strips in fabricating spiral high pressure vessels and winding one strip (80x4 mm) at a time. The maximum vessel we had fabricated is the one with a maximum diameter of Ø 1000 m and maximum wall thickness of 144 mm.

For ten years or so, we have been doing some research work on the state of steel strip winding vessels under stress, on theoretical analysis of elasticity and plasticity for realization of equal tensile strenth design, on upgrading the quality through improvement of strip winding technology and on the structure and strength of the vessels with holes on the cylinder wall. We have tested 5 vessels with diameters from Ø 450-1000 mm, the basic data are shown in Table 2.

From the test of vessels with holes on the cylinder wall, it can be seen that the location of maximum stress, the stress distribution around the hole and the stress decreasing zone are all similar to that of mono-wall vessels with holes. The maximum stress concentrated coefficient is within the design limit. The bursting pressure of the vessel can reach that of steel strip winding vessels without holes on the cylinder wall.

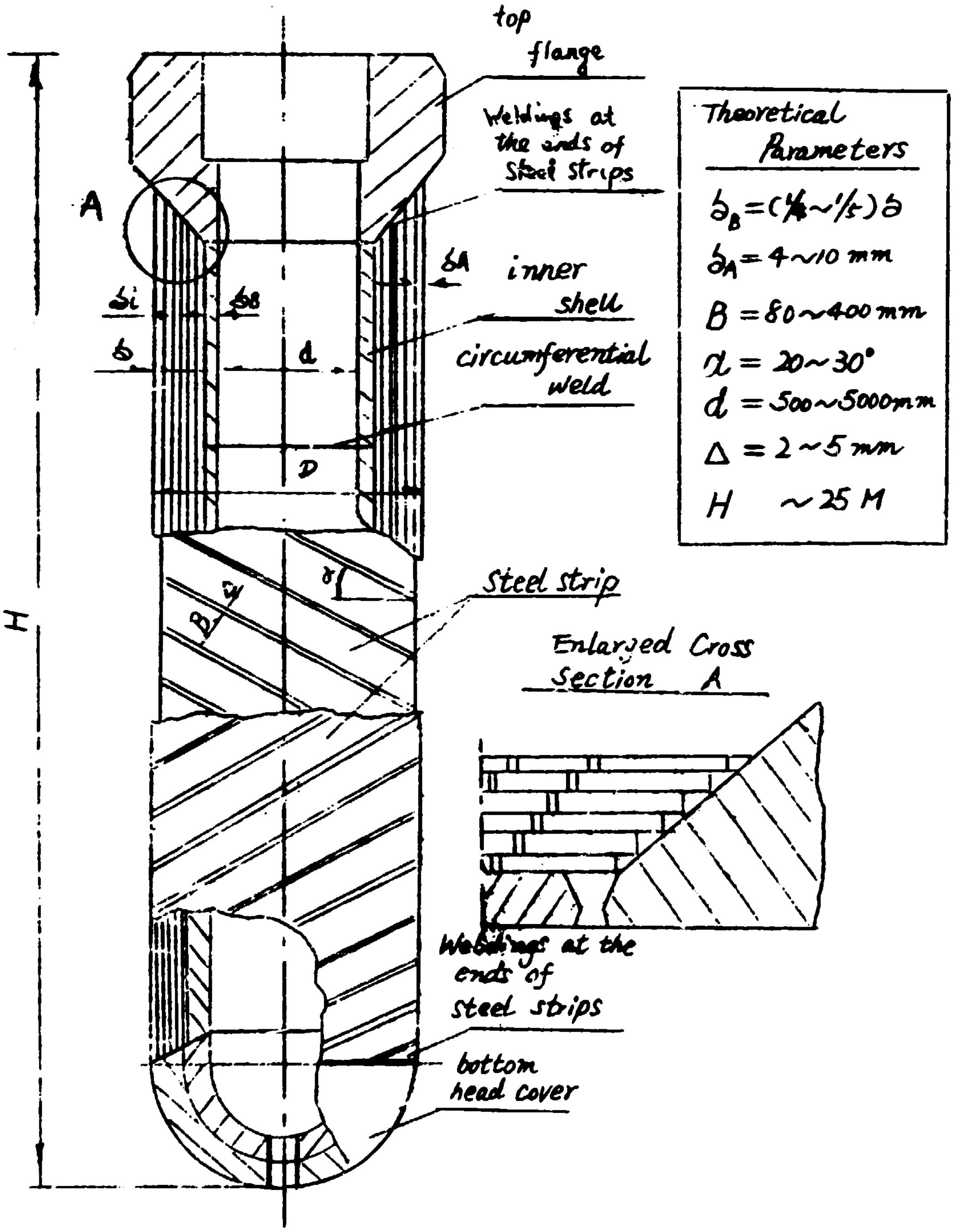

Fig.5. Diagram of steel strip winding structure vessel

Table 2 Burst Test of Steel Strip Winding High Pressure Vessels

serial No.	inside dia. mm	total wall thickness mm	inner thickness mm	shell material	steel thickness mm	strip material	diameter ratio K	bursting pressure actually measured kgf/cm^2
1	500	74	18	20_g	56=4x14	A_3R	1.290	975
2	500	54	18	16Mn	36=4x9	16Mn	1.216	1038
3	450	28	14	16Mn	14=3.5x4	16Mn	1.125	568
4	1000	108	28		80=4x10		1.216	920
5	500 with holes	56	16	20_g	40=4x10	16Mn	1.24	965

(Continue)

(continue table 2)

calculated bursting pressure kgf/cm^2		
4th strength theory	Faupel formula	medium diameter formula
1015	1150	1152
1160	1240	1210
631	646	618
1005	1130	1090
1025	1075	1078

(E) The manufacture of high pressure lined vessels for urea plants

The high pressure vessels for urea plants are usually with linings. In our country, 18-12 type super low carbon Austenic Stainless steel, ferrite Austenic biphase steel Cr 17Mn13Mo2N (A_4 steel) and technical pure titanium are generally used for urea vessel anti-corrosion linings.

Our country has manufactured a great number of urea plants with capacity from 360 tons/day to 800 tons per day. Now we have accumulated a wealth of experience through these years of practice.

There are many types of linings for urea high pressure vessels. According to user's request, we can supply mechanical linings, shrink fit linings, surfacinglinings, and stainless steel inner shell used as a lining for multi-layer bundle up vessels. For head linings, in addition to the mechanical linings and surfacing linings, there are explosion linings and stainless steel clad plate linings formed with hot stamping method.

1. Linings by mechanical method

This is the earliest type of linings we use for high pressure urea vessels. The inside wall of the cylinder to be lined is preferably machined first since a regular, smooth and clean surface is helpful to make the linings be tightly applied.

The longitudinal and circumferential welds, which are welded in the cylinder, should be mostly welded in padded form, as shown in Fig. 6 or with strap form, as shown in Fig. 7 as well. The weld seams should be inspected with coloured stains.

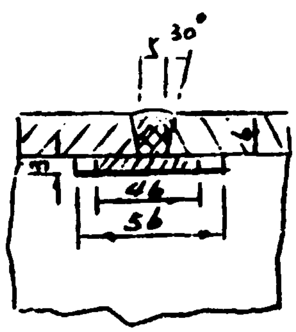

Fig.6 Padded form

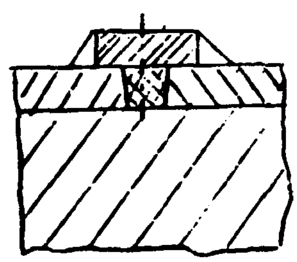

Fig.7 Strap form

2. Shrink fit linings

By this method, we have lined unit cylinders with a diameter Ø 1800 mm, for high pressure tube-box of urea plant, which has a capacity of 800 tons per day, with 10 mm thick titanium plate.

Plasm welding was employed for joining the plates and for longitudinal welds of the unit cylinders with welding by one side and forming by both side. The cylindrical lining should be padded with special inner supporting devices so as to control the ellipticity of the cylinder. The inner wall of the outer shell should be machined to ensure shrink range. The outer shell was heated before the shrinkage fit was carried out. The contact of the inner and outer shells was satisfactory after cooling down.

3. Surfacing linings

Surfacing linings are characterized with strong combination with the load bearing cylinder, high endurance of thermal stress and high fatigue resistance.

For large area surfacing welding, automatic submerged are welding is employed with stainless strip as an electrode.

4. Use stainless steel lining as inner shell for multi-layer bundle up vessels

The fabrication technology and technical requirements are the same with the inner shell of multilayer bundle up vessels.

Because different types of steels are used in welding circumferential weld of unit cylinders and in joining unit cylinder and head cover, it is necessary to perform certain welding test before actual welding begins. Fig. 8 is an example showing the circumferential weld structure and welding procedures in practical operation.

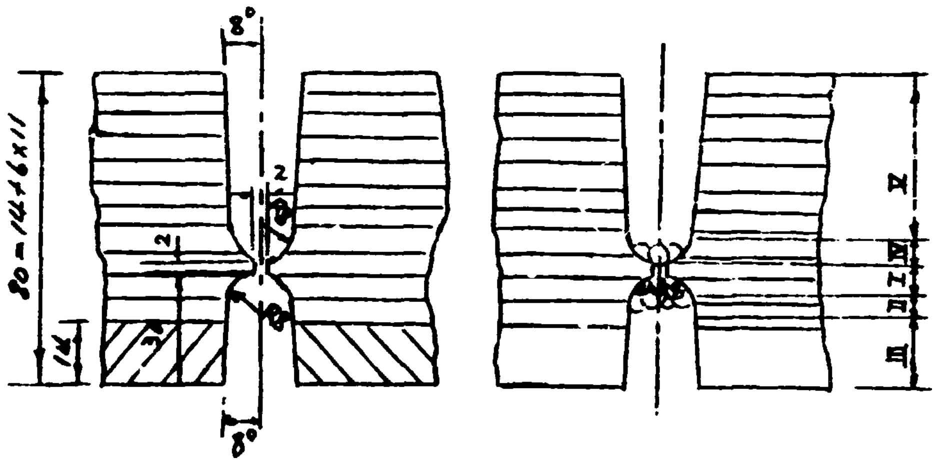

Fig.8.
Circumferential weld joint

I (1)-(4) Manual back running
II Transition layer zone
III Rustless layer zone
IV Manual carbon steel weld zone
V Automatic weld zone

5. Explosion linings

The linings should be assembled and welded in accordance with the configulation of head cover. Then the assembled lining is put into the head cover in the corresponding position and set tight against the head cover by the method of explosion. The space between lining and head cover should be made vaccum during explosion.

6. Hot stamping with titanium-steel clad plate

The semispherical head cover with a diameter of

Ø 1800 mm for urea plant is lined with (60+5) titanium steel clad plate fitted by direct hot stamping method.

After the titanium steel clad plate with a diameter of Ø 2850 mm, is fitted by exposive forming, the following inspections are carried out, i.e. the tightness of contact of layers, the loose area in the central dead zone, the surface quality of titanium plate, the shearing strength, the bending angle, the hardness of the titanium plate and the metallographic inspection of the connecting interface. The results show that the technical requirements have been met.

For vessel linings of urea plants, a certain amount of corrosion resistant thickness is required, i.e. 5 mm for plate linings measured from the contacting surface with medium; 3 mm for surfacing, calculated from the lowest point and 6 mm for the sealing sections. Within the above mentioned range of the thickness, the linings should be corrosion resistant and in conformation with the technical requirements.

The surface of the vessels fabricated of Austenic stainless steel or clad plate should be acid cleaned and passivated.

III. Quality assurance of the high pressure vessels

The quality of high pressure vessels directly affects the normal and safe operation of the plant. Therefore it is the first and foremost obligation for the manufacturers to ensure the quality of their products. In our country, in addition to the Safety Codes for the Manufacture of High Pressure Vessels, we also have established official supervision departments to guarantee the manufacture quality.

Table 3 shows the organization and functions of quality assurance systems set up in our high pressure vessel manufacturers to ensure the product quality.

The quality assurance system comprises two sections: quality control and quality inspection. These two sections have distinct but different functions. They coordinate and restrain each other. The system undertakes not only the inspection of finished products, but also the quality control before and during fabrication.

The final documents, which are attached to the finished product, are the appraisal of the product quality made by both the manufacturer and related inspection organizations. It is regarded as a comprehensive reflection of the design, fabrication and inspection of the product.

In our country, the final documents comprise:

a). Quality certificates

b). Detailed records (including lists of materials used, dimension check report, welding report of the welds, heat treatment report, X-ray inspection report, untrasonic inspection report and sample plate welding report);

c). General drawings and main structural drawings of the product;

d). Quality cdrtificates of raw materials

e). Report on any disagreement from the drawings.

Table. 3

- plant director
  - head of laboratory
    - sample processing
    - corrosion resistant test
    - chemical analysis
    - metallograhpic test
    - mechanical proper ty test
    - check of tools, instruments and apparutus
  - head of inspection section
    - heat treatment inspection
    - welding inspection
    - assemble quality inspection
    - supervision of material marking and delivery
    - raw material inspection
    - nondestructive test
  - head of technical section
    - Technical Service to end-users
    - qu-ality control education, quality accident information collection
    - compilation of engineering docu-ments, engi-neering test when necessary
    - assessment of welding technology, training and examination of welder-s
    - design, examin ation and approval of drawings, recommendations of criteria