First International Conference on

PRESSURE VESSEL TECHNOLOGY

Part III
DISCUSSION

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DISCUSSION

papers presented at the
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on Pressure Vessel
Technology

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The *Proceedings of the First International Conference on Pressure Vessel Technology* comprises three parts:

Part I – Design and Analysis
Part II – Materials and Fabrication
Part III – Discussion

The arrangement of the discussions in this volume follows the organization of material in Parts I and II. Papers numbered I-1 to I-51 were published in Part I, and papers numbered II-52 to II-108 in Part II.

Within the text of the discussions, numbers *in parentheses and numbers in square brackets refer to equations and bibliographical references (respectively) which were part of the papers as published in Parts I and II.* Letters *in parentheses and brackets refer to equations and references which are part of the discussions and closures. The same method is used to distinguish the figures and tables of the discussions from those which appeared with the papers.*

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Foreword

Part III of the *Proceedings of the First International Conference on Pressure Vessel Technology* includes the four lectures presented at the conference, which give a review of the state-of-the-art and possible future developments in main aspects of pressure vessel engineering; discussions pertaining to papers presented at the conference, submitted by conference participants for publication; and the Resume and Concluding Remarks, which provide summaries of the technical information presented, the significance of some of the trends in pressure vessel technology brought out at the conference and requirements for growth in pressure vessel technology. Part I, *Design and Analysis,* Part II, *Materials and Fabrication,* the booklet *Design Criteria of Boilers and Pressure Vessels,* along with Part III, together comprise the proceedings.

The major intent of the proceedings is to provide an international sampling of work in pressure vessel technology. New developments, insights, solutions, ideas, and techniques in analysis, design, computer methods, materials, fabrication, inspection, testing, components, and applications in pressure vessel technology are presented. Also discussed are current national or local practices, design philosophies, research goals, inspection concepts, etc.

Another objective of the publication of these volumes is to demonstrate that the area of pressure vessel technology is a broad, varied, and gratifying field of endeavor. It is hoped thereby to encourage the interest of engineering students and recent graduates to participate in this work.

A third goal of the International Conference and the publication of the proceedings is to recognize the field of pressure vessel technology as a distinct discipline. With this recognition, plans for additional international contacts and the continuing exchange of information should lead to further improvements in future pressure vessel technology conferences.

Irwin Berman, Chairman
ASME Task Force

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LECTURES

The Welding of Pressure Vessels, Past, Present and Future.

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I am deeply conscious of the honor to open this Conference and I appreciate the opportunity you have given me to remind you, if reminding you is necessary, that pressure vessels have not only got to be designed but they also have to be manufactured. I have not yet had the opportunity to study in detail all the excellent papers presented to you, but it seemed to me on first examination that the great majority of them deal with problems of design rather than manufacture. Experience however has taught us that manufacture cannot be entirely ignored in design if difficulties in fabrication and service are to be prevented. For convenience it may well be inevitable to divorce problems of design from those of manufacture but for ultimate success both must eventually be integrated.

WELDING – A DECISIVE STEP FORWARD

Today, welding, as by far the most widely used method of making pressure vessels, is very much taken for granted, and it might be useful to remind ourselves that the welded pressure vessel is not all that old. Prior to the introduction of welding, vessels could be made by rivetting, casting or forging. We have in our laboratory a number of fatigue testing machines composed essentially of pumps, valves and pressure vessels. Some of these are made by forging and one, the largest one, about 4 ft in diameter and perhaps 10 ft long, is a steel casting. It is probably about as large a pressure vessel as one may expect to make as a steel casting, and I shudder to think how many internal defects it contains. It has certainly never been X-rayed but has been in service at a fairly high pressure for nearly 20 years.

Larger vessels can, of course, be made by rivetting, but making rivetted vessels thicker than perhaps 1½ in. was not practical, and whilst much thicker vessels could be made by forging or casting, there was a very serious limitation on the length and diameter of vessel that could be made in this way. It is quite inconceivable that the chemical and petroleum industries and power generation could have developed to the present state of sophistication had welding not been introduced into pressure vessel manufacture.

I have, unfortunately, never had the opportunity to carry out the historical research necessary to ascertain who made the first welded pressure vessel, where it was made, whether it ever went into service and whether it was satisfactory in service and for how long it was used. One thing, however, is quite certain, that whoever took this decisive step was a very brave and enterprising man, who could not have foreseen the far reaching consequences this first attempt of making a welded pressure vessel would have on the development of the chemical and petroleum industry and he could certainly not have foreseen that without this first step the generation of power from atomic fission would forever have remained a physicist's dream.

It is equally certain that had the vessel, made and put into service by this unknown pioneer, been subjected to today's inspection and acceptance standards, it would never have left the fabricating shops.

THE PAST

A few years ago, we were given a vessel which had been in service for 17 years from 1937 to 1954 and which must have been fairly typical of these early welded pressure vessels (See Fig. 1). It was a 650 gallon liquefier for 220 lbs/sq in. pressure and an operating temperature of -35°C. It had not been stress relieved, but had been pressure tested at 375 lbs/sq in. After being taken out of service it was kept for seven years in reserve and proposed for

CO_2 storage in 1961. The insurance company, however, rejected it so that it had to be scrapped, and we were given it to find out how safe it was. The material was .48 in. thick. No information on the low temperature notch ductility of the material was available but it is unlikely that the material would have given 15 ft-lbs Charpy V-notch at -5°C. The test was carried out by cooling the vessel with a brine solution, and at a pressure at 500 lbs/sq in. at a temperature of -8°C it failed from a brittle crack originating from a severe flaw at the intersection of two welds at one end of the vessel. (Fig. 2). The crack ran for 8 in. before being arrested; the flaw surface was heat tinted, indicating that it had been present for over 25 years. It was located in an area of stress concentration sufficient to raise the local stress to at least the yield point of the material at the test pressure.

The longitudinal butt weld as well as the circumferential butt welds, as can be seen in Fig 1. had been provided with butt straps indicating a certain degree of suspicion in regard to the quality of the butt weld. Indeed, this suspicion was well justified because the butt weld showed virtually continuous lack of root fusion. There is no doubt at all that this vessel would never have been permitted to go into service had it been inspected in 1937 in the way it was inspected in 1961. It is amusing to contemplate the consequences for those industries entirely dependent today in their operations on welded pressure vessels if the same severe criteria for acceptance had been applied then as are being applied now.

ACCEPTANCE CRITERIA

The criteria to ensure safety and reliability used today are far more severe than can be justified by experience. The establishment of rational criteria for the acceptance of defects in the welds of pressure vessels is in fact one of the most urgent problems today, and such criteria can only be established on the basis of extensive experimental and theoretical investigations concerned with the effects of defects on fracture, both at low temperature and under conditions likely to result in fatigue. A large amount of data is now available largely from systematic investigations carried out in Belgium and the U.K., and the time has come when a serious attempt should be made to use this information for the promotion of rational and more sensible quality requirements.

THE PRESENT

The majority of vessels made by the fabricating industry in terms of production measured by total weight are made from mild steel in moderate thicknesses and of relatively simple shapes presenting no great problem in design or manufacture. The problems arise in the design and construction of vessels which, so far as total tonnage is concerned, represent

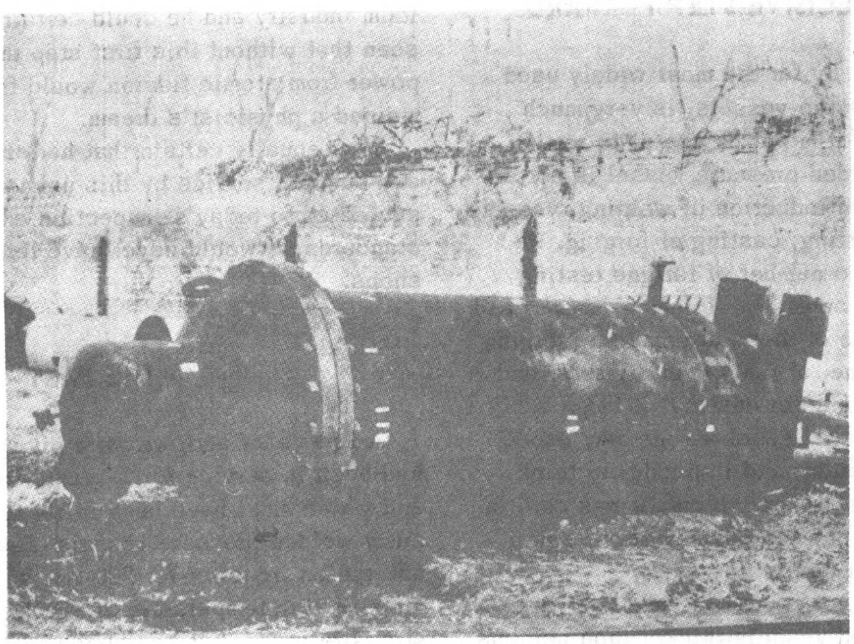

FIG. 1 LIQUEFIER – COMMISSIONED IN 1937 PRIOR TO DESTRUCTIVE PRESSURE TEST IN 1961.

only a fraction of the total output. Seen in perspective we must appreciate that real problems in pressure vessel design and manufacture arise only in a relatively small sector of the industry's total output, although this sector may well represent a larger proportion of the industry's output when measured in money terms rather than in tonnage terms, and that, of course, it is these more complex vessels that play a crucial part in modern processes. There is a trend towards the use of materials of increasing thicknesses and of higher strength and as a result quite difficult fabrication problems may arise. At the same time there is a steady increase in the severity of service conditions resulting from the sophistication and complexity of modern processes both in the power generating industry and in the oil, chemical and gas industries.

CONSUMABLES

Practically all the welding processes used in the fabrication of pressure vessels require the use of consumables, and the problems arising in the design and development of consumables to meet increasingly severe requirements imposed by insurance and inspection authorities are increasing. Even at this point in time the fabricator is frequently confronted with almost a worldwide search for welding consumable which will permit him to meet the requirements for high temperature or low temperature properties in the weld metal or heat affected zone of welds in pressure vessels fabricated from alloy or high tensile steels. One flux-wire combination for submerged arc welding may meet the requirements for tensile and bend tests but fail to meet the requirements of the Charpy V-notch test. For a different combination the situation may be reversed so that the fabricator may have to carry out a large amount of ad hoc experimental work with different consumables and variations in welding procedure before he succeeds.

There is much room for some degree of rationalization of mechanical test requirements. There are some today that go back in history a long time and make little sense today. This problem has received relatively little attention and there is a curious and paradoxical divergence between the development and refinement of methods of stress analysis and the completely stagnant situation in relating calculated stresses to the properties established by conventional tests and the relevance of these tests to the real problem of the safety of the vessel.

There is also an urgent need to fill in the large gaps in our knowledge on the relation between the required test figures for weld metal and heat affected zones and the many metallurgical chemical and process variables of each welding process. The scientific understanding of the factors which determine the properties the fabricator has to achieve to satisfy insurance and inspection bodies is still so rudimentary that it is impossible to provide tailor-made consumables for a given process and a given material

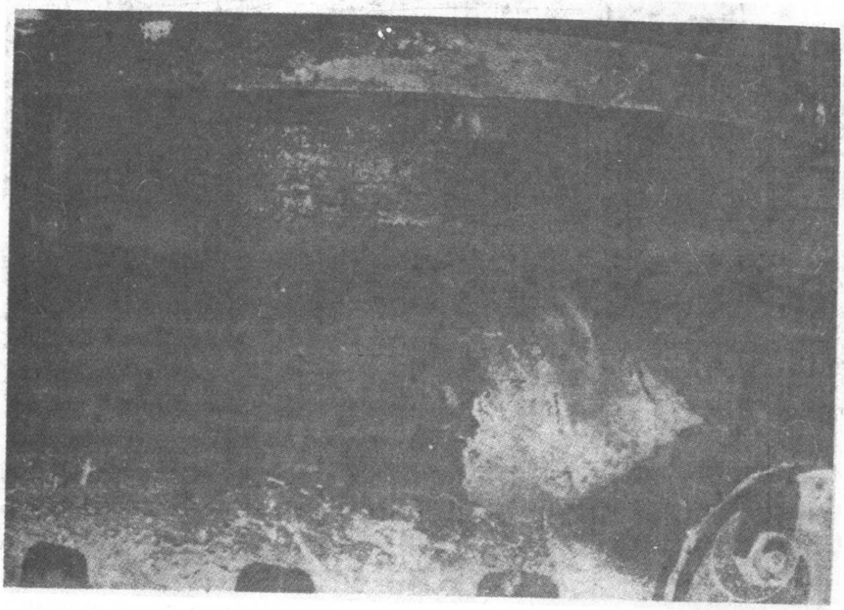

FIG. 2 SHORT CRACK AT FAILURE OF VESSEL SHOWN IN FIG. 1 AFTER PRESSURE TEST AT − 8 °C AT MORE THAN TWICE DESIGN PRESSURE.

on demand without costly and very lengthy ad hoc experimentation.

STRESS RELIEF

Most pressure vessel specifications require as part of the acceptance procedure a stress relieving heat treatment and a pressure test irrespective of the service conditions and the material used. There is now considerable evidence to indicate that in certain materials, at any rate, the effect of a stress relieving heat treatment is not entirely beneficial and may in fact in some materials result in fairly drastic deterioration in mechanical properties, particularly where stress relieving temperature is not rigorously controlled within narrow limits. On the other hand, a pressure test at a pressure only moderately in excess of the maximum working pressure has been shown to reduce the risk of brittle fracture very considerably, in most cases, and could very well be considered as an alternative to a stress relieving heat treatment where this is mandatory primarily as a safeguard against brittle fracture.

THE FUTURE

When one looks back a few decades to the time when welded pressure vessels were first introduced, and attempts to forecast the future from the experience of the past, one is tempted to predict that vessels will continue to increase in size and that construction on site will become increasingly more important. This will undoubtedly accentuate these problems and require the development of improved site welding methods. This is already taking place in shipbuilding where large sub-assemblies are joined on the berth.

There are at present severe limitations on the quality of thick material produced by steelmakers using existing steel-making processes and equipment. There may therefore be an increasing emphasis in the future on the use of wound or multilayer vessels and this development will demand better solutions for the design and fabrication problems posed by the reinforcement of openings and nozzles than have been adopted hitherto. At the same time, pressure vessel steels of better quality may become available with the increasing introduction of vacuum casting and electro slag refining in steelmaking practice. It seems perhaps logical in this context to consider whether thick vessels could be made both more economically and of superior quality than they could be made from heavy steel plate by using electro slag welding only and by making the whole vessel from weld metal. Experiments to this effect are in progress in Japan.

There are increasing difficulties now, as has already been pointed out, in meeting high temperature or low temperature requirements for weld metal and heat affected zones in vessels made by well established arc welding processes, and there may well be

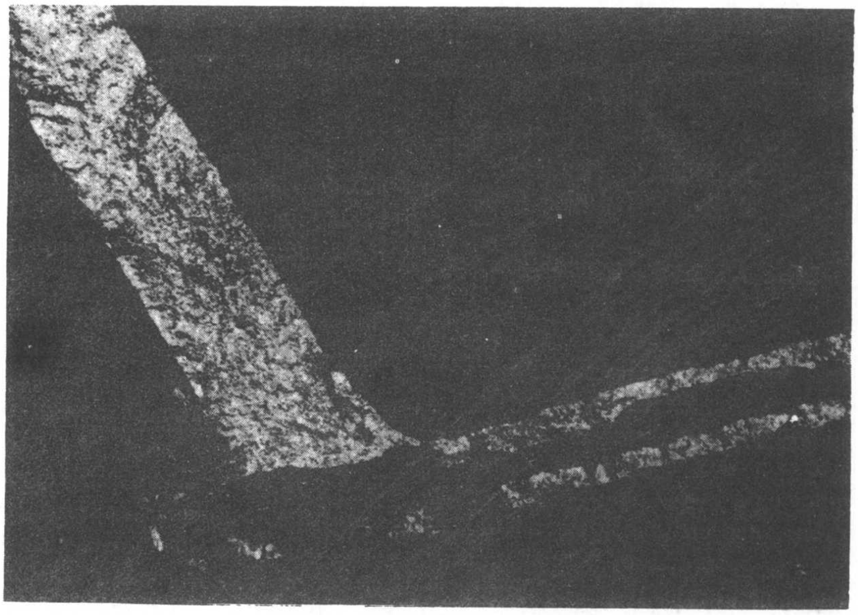

FIG. 3 HEAT-TINTED FLAW AT WELD INTERSECTION FROM WHICH FAILURE INITIATED. THIS FLAW HAD BEEN PRESENT SINCE THE VESSEL WAS COMMISSIONED AND HAD BEEN IN SERVICE AT 220 LBS/SQ. IN. FOR 17 YEARS.

considerable scope in the fabrication of pressure vessels for processes such as friction welding and electron beam welding. The application of these two processes to pressure vessel fabrication would require very large investments in equipment and more accurate fit-up in fabrication than is customary at present. Both processes, however, make practically no demand on skill and are much more readily controllable than conventional arc welding processes. Friction welding in particular produces joints of a standard of quality quite beyond the limits of attainment with any other welding processes. The narrow fused and heat affected zones that could be obtained in electron beam welding, and the high welding speeds attainable, make this process particularly interesting for the future despite the high capital costs of the equipment. It may eventually be found to be far more economical than present processes, particularly, if as is not unlikely, weld quality could be controlled to such a degree that subsequent non-destructive examination of the joint became unnecessary. These developments may well have to receive quite urgent consideration in the near future as the demand for skilled welders rises with the level of their remuneration.

A gradual change from conventional fusion processes to such processes as electron beam welding will be required as the demand for vessels made of materials other than our more conventional pressure vessel steels increases. The chemical industry has entered a phase of extraordinarily rapid change so that plants built today may be obsolete within a very few years after commissioning. This change will impose increasingly severe demands. Vessels made from ultra high strength steels and either made or clad with materials still considered somewhat exotic today, such as titanium, vandium and tantalum, will be required in increasing numbers. These developments will confront the fabricating industry with a whole range of new welding problems which are unlikely to be solved without considerable further development of welding technology.

Application of High Strength Steels for Pressure Vessels in Japan

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I would like to review the present situation of high strength steels for welded structures and then to outline the current status of development and production efforts in their application for pressure vessels in Japan.

From 1958 to 1967 the output of high strength steel plate has increased by a factor of about fifteen and the production in this year is expected to be approximately one million tons, most of it to be used in welded structures. The percentage occupied by high-strength steel plates in the total products of ordinary steel plates was 7.6 percent last year, but it is expected this will increase further in the future. Moreover, there has recently been a remarkable increase in demand for steel with good low-temperature properties.

The increase in the production of high-strength steel has been attributable largely to advances made in welding techniques and to progress made in research into the weldability and notch toughness of steel.

The standards for high-strength steel for welded structures are established by the Japan Welding Engineering Society.

From about 1952, research concerning Si-Mn type high-strength steel with a tensile strength of about 50kg/mm^2 became quite active.

During the initial period, high-strength steels of 50kg/mm^2 class were manufactured and marketed by the individual iron and steel manufacturers on the basis of their own standards, and under their own trade names. However, in 1959 national standards were established, and the groundwork was laid for widespread use of these steels on a unified basis.

At present they were widely used not only in pressure vessels, but also in bridges, in architecture, in shipbuilding, in machinery and so on.

Beginning about 1957, there has been a tendency for increasing quantities of Liquefied Petroleum Gas (LPG) to be used in Japan. A need was felt for economical high-strength steel to be used in the LPG storage containers, tank lorries and tankers. Utilizing the Derever type hardening equipment, which had been perfected in the Untied States, Japanese iron and steel manufacturers developed in rapid succession their own types of steels of 60 kg/mm^2 tensile strength, each one having a unique chemical composition.

Since they are comparatively inexpensive in relation to their strength, and have excellent notch toughness and weldability, steels of this type are now used in almost all kinds of steel structures including high-pressure vessels.

In 1961, a need arose for large-capacity city gas holders, and plans were made for designing spherical tanks with a capacity of approximately 100,000 Nm^3. At first, steel with a tensile strength of 80 kg/mm^2 containing nickel and vanadium was used. But to avoid high-cost alloying, non-nickel and non-vanadium steel was developed. In 1966, this steel made possible the production of large-capacity, high-pressure spherical tanks for city gas.

This steel also has an excellent notch toughness at low-temperatures, and it is being used as a high-strength steel for low-temperature service at -30°C.

Table 1 Main features of WES (Welding Engineering Standard) 135, high-strength steel plate for welded structure

Designation	Yield Point kg/mm^2	C % max	P % max	S % max	Plate Thickness mm	Charpy V-notch Min Energy kg-m	Temp. °C	Tensile Strength kg/mm^2	Elongation %	Tensile Test Piece No.	Ratio of Bend Radius to Thickness of Specimen (Angle of Bend: 180°)	Max Ceq %	Max HAZ Hardness HV
HW36	36	0.20	0.035	0.040	<13			53-65	23	5		0.48	380
					13≤ <21	4.8	+15		29	5	< 32mm 1.5		
									16	1	≥ 32mm 2.0		
					21≤	4.8			23	4			
									18	1			
HW40	40	0.20	0.035	0.040	<13			57-70	22	5	as above	0.49	390
					13≤ <21	4.8	+10		28	5			
					21≤	4.8	0		22	4			
HW45	45	0.18	0.035	0.040	<13			60-72	20	5	as above	0.50	400
					13≤ <21	4.8	+5		26	5			
					21≤	4.8	−5		20	4			
HW50	50	0.18	0.035	0.040	<13			62-75	19	5	as above	0.54	415
					13≤ <21	4.8	+5		25	5			
					21≤	4.8	−10		19	4			
HW56	56	0.18	0.035	0.040	<13			68-82	18	5	as above	0.58	430
					13≤ <21	4.8	0		24	5			
					21≤	4.8	−10		18	4			
HW63	63	0.18	0.035	0.040	<13			74-85	17	5	as above	0.60	440
					13≤ <21	4.0	−5		23	5			
					21≤	4.0	−15		17	4			
HW70	70	0.18	0.030	0.035	<13			80-95	16	5	as above	0.62	450
					13≤ <21	3.6	−5		22	5			
					21≤	3.6	−15		16	4			
HW80	80	0.18	0.030	0.035	<13			88-105	14	5		0.74	470
					13≤ <21	2.8	−10		20	5	< 32mm 2.0		
					21≤	2.8	−20		14	4	≥ 32mm 2.5		
HW90	90	0.18	0.030	0.035	<13			97-115	13	5	as above	0.80	480
					13≤ <21	2.8	−15		18	5			
					21≤	2.8	−25		13	4			

Tensile test piece: No. 1 Full thickness rectangular section specimen with 200mm gauge length
No. 5 Full thickness 25mm width rectangular section specimen with 50mm gauge length
No. 4 14mm dia round section specimen with 50mm gauge length

Ceq: $C + 1/6 \cdot Mn + 1/24 \cdot Si + 1/40 \cdot Ni + 1/5 \cdot Cr + 1/4 \cdot Mo + 1/14 \cdot V$

In 1963, a high-strength steel of the 100 kg/mm^2 class capable of being welded in the field was produced. This steel has approximately the same chemical composition as nickel-containing 80 kg/mm^2 high-strength steel, but it has been given the so-called I-N treatment. This is a treatment designed to improve the strength and toughness by making use of the fine precipitation of nitrides. This steel has been also used for high-pressure spherical tanks.

Efforts have also been devoted to the development of types of inexpensive high-strength steels other than those mentioned above. For example a niobium semi-killed steel with a yield strength of 36 kg/mm^2 was produced in 1963.

There is also an increasing demand for high-strength steel with weathering resistance properties. More than 50,000 tons were manufactured during the past year.

Table 2 WES specification of structural steel plates for low-temperature applications

Chemical composition	Not specified
Mechanical properties	
Tensile strength	Not specified
Yield point	Not specified
Elongation, percent	When the nominal yield point is less than 32 kg/mm^2, $\geqq -3\sigma_y/8 + 50\sqrt{A/L} + 22$ When the nominal yield point is equal or greater than 32 kg/mm^2 $\geqq 360/(\sigma_y - 8) + 50\sqrt{A/L} - 5$ σ_y : nominal yield point of steel, kg/mm^2 A : sectional area of specimen, mm^2 L : gauge length of specimen, mm
Bending properties	(see below)

Bending properties:

Nominal Y. P.	Plate thick., mm	Ratio of bend radius to plate thick.
<80 kg/mm^2	<32	1.5
	≥32	2.0
≥80	<32	2.0
	≥32	2.5

Charpy V-notch impact properties	Criterion vE.1/2; The half of the fully sheared max. impact value Test: The tested Charpy impact value must be equal or greater than $vE\cdot 1/2$ at the test temperature given by the tables. These test temperatures are determined by design temperature, design stress, and plate thickness of the steel. Class: Two classes of steel toughness are specified: one is for arresting use and the other for general use. The arresting use class steel can arrest the brittle fracture of 100 mm, and the general use class 10 mm in length.