■ 高等学校理工科化学化工类规划教材

FUNDAMENTAL CHEMICAL PROCESS EQUIPMENT

化工设备机械基础（双语版）

周一卉　喻健良　主编

大连理工大学出版社
DALIAN UNIVERSITY OF TECHNOLOGY PRESS

■ 高等学校理工科化学化工类规划教材

FUNDAMENTAL CHEMICAL PROCESS EQUIPMENT

化工设备机械基础（双语版）

主编　周一卉　喻健良

大连理工大学出版社
DALIAN UNIVERSITY OF TECHNOLOGY PRESS

图书在版编目(CIP)数据

化工设备机械基础 ：双语版 / 周一卉，喻健良主编.
— 大连 ：大连理工大学出版社，2013.8
ISBN 978-7-5611-8146-1

Ⅰ.①化… Ⅱ.①周… ②喻… Ⅲ.①化工设备—双语教学—高等学校—教材 ②化工机械—双语教学—高等学校—教材 Ⅳ.①TQ05

中国版本图书馆 CIP 数据核字(2013)第 195956 号

大连理工大学出版社出版
地址:大连市软件园路 80 号　邮政编码:116023
发行:0411-84708842　邮购:0411-84703636　传真:0411-84701466
E-mail:dutp@dutp.cn　URL:http://www.dutp.cn
大连力佳印务有限公司印刷　　大连理工大学出版社发行

幅面尺寸:185mm×260mm　　印张:18.75　　字数:456 千字
2013 年 9 月第 1 版　　2013 年 9 月第 1 次印刷

责任编辑:于建辉　　责任校对:庞　丽
封面设计:季　强

ISBN 978-7-5611-8146-1　　定　价:38.00 元

前　言

化工设备机械基础是一门面向工艺类、环境类和其他非过程装备与控制工程专业学生开设的，介绍过程装备基本理论与设计规范的技术基础课。课程内容覆盖了法规、标准、过程装备设计基本理论与规范，以及典型塔设备与换热器设备的设计方法。

由刁玉玮教授等编著的《化工设备机械基础》自1988年出版以来，受到了广大读者，特别是相关高校师生的厚爱，许多高校从第1版起就将之选做教材并沿用至今。该书第5、6、7版分别入选普通高等教育“十五”、“十一五”和“十二五”国家级规划教材。

为了适应人才培养的多样化要求，我们在刁玉玮编著的《化工设备机械基础》的基础上，总结多年双语教学经验，编写了 *Fundamental Chemical Process Equipment*（双语版）。本书在编写过程中，保持了中文版教材的特色，并注意英文表达的准确、适度、实用。本书具有如下特色：

(1)重视专业术语的准确表达和较为地道的英文表述，提高英语实际运用能力。

(2)加强基本知识、基本理论和基本概念，同时注重规范设计与实用方面的要求。

(3)体系完整。本书分为三篇：化工设备材料篇，包括化工设备材料及其选择；化工容器设计篇，包括容器设计的基本知识、内压薄壁容器的应力分析、内压薄壁圆筒与封头的强度设计、外压圆筒与封头的设计、容器零部件；典型化工设备的机械设计篇，包括管壳式换热器的机械设计和塔设备的机械设计。基本概括了进行化工设备设计所必备的基础，为理解化工设备设计及进一步学习与应用提供了条件。

(4)本着服务教学、与时俱进的原则，参照了ASME、我国国家标准及行业现行最新标准，注重国内外标准的对应与衔接。主要参考标准与法规包括 ASME BPVC Section Ⅷ Division 1—2008、GB 150.1～4—2011《压力容器》、GB 151—1999《管壳式换热器》，NB/T 47020～47027—2012《压力容器法兰、垫片、紧固件》、JB/T 4710—2005《钢制塔式容器》、HG/T 20592～20635—2009《钢制管法兰、垫片、紧固件》，以及 TSG R0004—2009《固定式压力容器安全技术监察规程》等。

(5)在内容编排上，考虑到许多高校有学时数减少的趋势，加之本书的适用专业范围为化工工艺、环境、制药等专业，因此，本书删去了中文版中较为繁杂的公式推导，着重于基本概念、基本理论与工程规范标准的掌握与应用。教师可根据具体情况进行选用。

(6)本书各章配有适量的例题和习题，将计算与设计所需的必要数据、标准纳入附录，使学生体验设计计算的全过程，尽快培养起工程观念。同时，将本书编写中涉及的所有标准列入参考文献，方便检索查阅。

本书1～8章及附录由周一卉副教授编写，全书由喻健良教授统稿并定稿。伊军高级工程师对本书编写提出了宝贵意见，靳晓萌、李默、王莎和王宇楠同学参与了部分章节的校译工作，在此一并表示谢意！

本书可作为高等学校化工、环境、生物、制药等相关专业学生学习化工容器与设备机械设计基础知识的双语教材，也可供有关工程技术人员参考。

由于编者水平有限，其中的不足在所难免，欢迎广大读者提出宝贵意见并给予指正。读者在使用本书的过程中有任何意见和建议，请通过以下方式与我们联系：

邮箱 jcjf@dutp.cn

电话 0411-84707962 84708947

编 者

2013年8月

目 录

Ⅰ Materials of Chemical Equipment
化工设备材料

Chapter 1 Materials of Chemical Equipment and Selection 化工设备材料及其选择 …… 1

1.1 General 概 述 / 1

1.2 Material Properties 材料的性能 / 2

1.2.1 Mechanical Properties 力学性能 / 2

1.2.2 Physical Properties 物理性能 / 8

1.2.3 Chemical Properties 化学性能 / 9

1.2.4 Technical (Processing) Properties 加工工艺性能 / 10

1.3 Classification of Metal Materials 金属材料的分类 / 10

1.4 Alloy of Carbon and Iron 铁碳合金 / 11

1.5 Carbon Steel and Cast Iron 碳钢和铸铁 / 12

1.5.1 Carbon Steel 碳 钢 / 12

1.5.2 Cast Iron 铸 铁 / 15

1.6 Steel for Boilers and Pressure Vessels 锅炉压力容器用钢材 / 18

1.6.1 Effects of Alloy Elements on Steel Performances 合金元素对钢性能的影响 / 18

1.6.2 Steel Plates for Boilers and Pressure Vessels 锅炉压力容器用钢板 / 20

1.7 Heat Treatment of Steel 钢材的热处理 / 22

1.8 Nonferrous Materials 有色金属 / 24

1.8.1 Aluminum and Its Alloy 铝及其合金 / 24

1.8.2 Copper and Its Alloy 铜及其合金 / 26

1.8.3 Lead and Its Alloys 铅及其合金 / 27

1.8.4 Titanium and Its Alloys 钛及其合金 / 27

1.9 Nonmetal Material 非金属材料 / 27

1.9.1 Inorganic Nonmetal Material 无机非金属材料 / 28

1.9.2 Organic Nonmetal Material 有机非金属材料 / 28

1.10 Corrosion and Protection of Chemical Equipment 化工设备的腐蚀及防腐措施 / 29

1.10.1 Evaluation of Metal Corrosion 金属腐蚀的评定 / 29

1.10.2 Corrosion of Metal 金属的腐蚀 / 30

1.10.3 Corrosion Resistant Measures 金属设备的防腐措施 / 34

1.11 Selection of Material 化工设备材料的选择 / 36

1.11.1 General Selection Principles 一般原则 / 36

1.11.2 Example of Material Selection 选材举例 / 36

Summary / 37
Question and Discussion / 38

Ⅱ Design of Chemical Equipment
化工容器设计

Chapter 2 Basic for Vessel Design 容器设计的基本知识 ······················ 40
2.1 Classification and Structure of Vessels 容器的分类与结构 / 40
2.1.1 Classification of Vessels 容器的分类 / 40
2.1.2 Structure of Vessels 容器的结构 / 43
2.2 Standardization of Vessel Part 容器零部件的标准化 / 44
2.2.1 Significance of Standardization 标准化的意义 / 44
2.2.2 Basic Parameters of Standardization 标准化的基本参数 / 44
2.3 Safety Inspection of Pressure Vessel 压力容器的安全监察 / 45
2.3.1 Scope of Safety Inspection 安全监察的范围 / 45
2.3.2 Standards and Regulations of Pressure Vessel 压力容器相关标准和法规 / 46
2.4 Requirements for Pressure Vessel Design 容器机械设计的基本要求 / 46
Summary / 47
Question and Discussion / 47
Chapter 3 Stress Analysis of Thin-Walled Internal Pressure Vessel
内压薄壁容器的应力分析 ·· 49
3.1 Stress Analysis of The Rotating Shell—Membrane Stress Theory
回转壳体的应力分析——薄膜应力理论 / 49
3.1.1 Thin-Walled Vessels and Its Stress Distribution Characteristics
薄壁容器及其应力分布特点 / 49
3.1.2 Basic Concepts and Hypothesis 基本概念和假设 / 50
3.1.3 Longitudinal Stress and Circumferential Stress 经向应力和环向应力 / 51
3.1.4 Limitation of Membrane Stress of Symmetrical Rotating Thin-Walled Shell
轴对称回转薄壳薄膜理论的应用范围 / 54
3.2 Application of Membrane Theory 薄膜理论的应用 / 54
3.2.1 Cylindrical Vessel with Internal Pressure 受气体内压的圆筒形容器 / 54
3.2.2 Spherical Vessel with Internal Pressure 受气体内压的球形容器 / 55
3.2.3 Ellipsoid Shell with Internal Pressure 受气体内压的椭球壳体 / 55
3.2.4 Conical Shell with Internal Pressure 受气体内压的锥形壳体 / 57
3.2.5 Examples 算 例 / 58
3.3 Edge Stress of Internal Pressure Cylinder 内压圆筒边缘应力 / 59
3.3.1 Concept of Edge Stress 边缘应力的概念 / 59
3.3.2 Characteristics of Edge Stress 边缘应力的特点 / 60
Summary / 61
Question and Discussion / 61

Chapter 4　Strength Design of Internal Pressure Vessel and Head
内压薄壁容器与封头的强度设计 …………………………………………… 63
4.1　Basics of Strength Design　强度设计的基本知识 / 63
4.1.1　The Design Criterions of Elastic Failure　弹性失效设计准则 / 63
4.1.2　Strength Theory and Corresponding Strength Condition
强度理论及其相应的强度条件 / 64
4.2　Strength Design of Cylinder and Sphere　内压薄壁圆筒壳和球壳的强度设计 / 65
4.2.1　Strength Calculating Formulas　强度计算公式 / 65
4.2.2　The Determination of Designed Parameters　设计参数的确定 / 67
4.2.3　The Thickness and Minimum Thickness of Vessels　容器的厚度和最小厚度 / 75
4.2.4　Pressure Test and Strength Check　压力试验及其强度校核 / 76
4.2.5　Examples　算　例 / 79
4.3　The Design of Internal Pressure Cylinder Head　内压圆筒封头设计 / 81
4.3.1　Semi-sphere Head　半球形封头 / 82
4.3.2　Elliptical Head　椭圆封头 / 82
4.3.3　Dished Head　碟形封头 / 83
4.3.4　Spherical End Head　球形封头 / 85
4.3.5　Conical Head　锥形封头 / 86
4.3.6　Flat Head　平板封头 / 88
4.3.7　Example　算　例 / 90
4.3.8　The Selection of Head　封头的选用 / 92
Summary / 96
Question and Discussion / 96
Chapter 5　Design of External Pressure Vessel and Head　外压圆筒与封头设计 …… 98
5.1　General　概　述 / 98
5.1.1　Buckling of External Pressure Vessel　外压容器的失稳 / 98
5.1.2　Buckling Type of External Pressure Vessel　容器失稳类型 / 98
5.2　Critical Pressure　临界压力 / 99
5.2.1　Parameters Affecting Critical Pressure　影响临界压力的因素 / 100
5.2.2　Long Cylinder, Short Cylinder and Rigid Cylinder
长圆筒、短圆筒和刚性圆筒 / 101
5.2.3　Theoretical Computation Formula of Critical Pressure
临界压力的理论计算公式 / 102
5.2.4　Critical Length　临界长度 / 103
5.3　Engineering Design of External Pressure Cylinder　外压圆筒的工程设计 / 103
5.3.1　Design Criterion　设计准则 / 103
5.3.2　Nomography Design Method of External Pressure Cylinder
外压圆筒壁厚设计的图算法 / 104
5.3.3　Pressure Test of External Pressure Vessel　外压容器的试压 / 111
5.3.4　Example　算　例 / 112

5.4 Design of Spherical Shell and Convex Head under External Pressure
外压球壳与凸形封头的设计 / 113
5.4.1 Design of Spherical Shell and Head under External Pressure
外压球壳和封头的设计 / 113
5.4.2 Design of Convex Head under External Pressure 凸面受压封头的设计 / 113
5.4.3 Example 算 例 / 114
5.5 Design of Reinforcing Ring for Cylinder under External Pressure
外压圆筒加强圈的设计 / 115
5.5.1 Function and Structure of Reinforcing Rings 加强圈的作用与结构 / 115
5.5.2 Distance Between Reinforcing Rings 加强圈的间距 / 115
5.5.3 Dimension Design of Reinforcing Ring 加强圈的尺寸设计 / 116
5.5.4 Connections Between Cylinder and Reinforcing Ring
加强圈与圆筒间的连接 / 116
5.5.5 Example 算 例 / 117
Summary / 119
Question and Discussion / 119
Chapter 6 Components of Pressure Vessel 容器零部件 ······························ 121
6.1 Flange Connection 法兰连接 / 121
6.1.1 Structure of Flange Connection and Seal Principle
法兰连接结构与密封原理 / 121
6.1.2 Structure and Classification of Flange 法兰的结构与分类 / 122
6.1.3 Effective Factors on Flange Seal Performance
影响法兰密封的主要因素 / 124
6.2 Standards and Selection of Flange 法兰的标准及选用 / 128
6.2.1 Flanges for Pressure Vessels 容器法兰 / 128
6.2.2 Flanges for Pipes 管道法兰 / 132
6.3 Support of Pressure Vessel 容器支座 / 137
6.3.1 Support of Horizontal Vessel 卧式容器支座 / 137
6.3.2 Support of Vertical Vessel 立式容器支座 / 140
6.4 Opening Reinforcement 容器的开孔补强 / 141
6.4.1 Stress Concentration 应力集中现象 / 142
6.4.2 Principle and Structure of Opening Reinforcement
开孔补强的原则和结构 / 142
6.4.3 Equal-Area Design of Opening Reinforcement
开孔补强的等面积设计方法 / 144
6.5 Other Attachments of Pressure Vessel 其他容器附件 / 148
Summary / 149
Question and Discussion / 150

Ⅲ Mechanical Design of Typical Chemical Equipment 典型化工设备的机械设计

Chapter 7 Mechanical Design of Tubular Heat Exchanger
管壳式换热器的机械设计 ······ 151

7.1 General 概 述 / 151
7.1.1 Structure and Components of Tubular Heat Exchanger 管壳式换热器的结构和主要零部件 / 151
7.1.2 Classification of Tubular Heat Exchanger 管壳式换热器的分类 / 152
7.1.3 Mechanical Design of Tubular Heat Exchanger 管壳式换热器的机械设计内容 / 153
7.2 Selecting Heat Exchange Tube and Tubesheet Joint 换热管的选用及其与管板的连接 / 154
7.2.1 Selecting Heat Exchanger Tube 换热管的选用 / 154
7.2.2 Tube-to-Tubesheet Joint 管子与管板的连接 / 155
7.3 Structure of Tubesheet 管板结构 / 158
7.3.1 Tube Layout 管子排列形式 / 158
7.3.2 Tube Pitch 管间距 / 160
7.3.3 Calculation for Tubesheet 管板受力及其设计方法 / 161
7.3.4 Tube Passes and Joint of Tubesheet and Partition 管程的分程及管板与隔板的连接 / 161
7.3.5 Joint of Tubesheet and Shell 管板与壳体的连接 / 163
7.4 Baffle Plate, Support Plate, By-pass Baffle Plate and Liquid Blocking Plate 折流板、支撑板、旁路挡板和拦液板 / 164
7.4.1 Baffle Plate and Support Plate 折流板与支撑板 / 164
7.4.2 By-pass Baffle Plate 旁路挡板 / 167
7.4.3 Liquid Blocking Plate 拦液板 / 168
7.5 Thermal Stress 温差应力 / 168
7.5.1 Thermal Stress Caused by Wall Temperature Difference of Tube and Shell 管壁与壳壁温差引起的温差应力 / 168
7.5.2 Calculation of Pull-out Load 管子拉脱力计算 / 169
7.5.3 Compensation of Thermal Stress 温差应力的补偿 / 172
7.6 Channel and Shell Tubes 管箱与壳程接管 / 174
7.6.1 Channel 管 箱 / 174
7.6.2 Shell Tubes 壳程接管 / 174
Summary / 175
Question and Discussion / 176

Chapter 8 Mechanical Design of Steel Vertical Vessels Supported by Skirt
塔设备的机械设计 ······ 177

8.1 Mechanical Design of Column and Skirt 塔体和裙座的机械设计 / 178

8.1.1 Thickness Calculation of Column 塔体厚度的计算 / 178
8.1.2 Design of Skirt 裙座设计 / 189
8.2 Mechanical Design Example of Column and Skirt 塔体和裙座的机械设计举例 / 196
8.2.1 Design Conditions 设计条件 / 196
8.2.2 Calculation of Column Body and Head Thickness
按计算压力计算塔体和封头厚度 / 198
8.2.3 Calculation of Column Mass Loads 塔设备质量载荷计算 / 198
8.2.4 Calculation of Wind Load and Wind Bending Moment
风载荷与风弯矩计算 / 200
8.2.5 Calculation of Seismic Bending Moment 地震弯矩计算 / 202
8.2.6 Calculation of Eccentric Bending Moment 偏心弯矩计算 / 203
8.2.7 Axial Stress Caused by Loads 各种载荷引起的轴向应力 / 203
8.2.8 Strength and Stability Check of Dangerous Section of Column Body and Skirt
塔体和裙座危险截面的强度与稳定校核 / 204
8.2.9 Stress Check in Hydrostatic Pressure Test and Installation
塔体水压试验与吊装时的应力校核 / 206
8.2.10 Design of Base Ring 基础环设计 / 207
8.2.11 Calculation of Anchor Bolt 地脚螺栓计算 / 208
8.3 General Structure of Tray Column and Packed Column
板式塔和填料塔的整体结构 / 209
8.3.1 General Structure of Tray Column 板式塔整体结构 / 209
8.3.2 General Structure of Packed Column 填料塔整体结构 / 210
Summary / 211
Question and Discussion / 211

Appendix 附 录 …… 213
附录 1 常用金属材料的物理性能 /213
附录 2 锅炉和压力容器用钢板的化学成分和力学性能 /214
附录 3 钢板、钢管、锻件和螺栓的高温力学性能 /216
附录 4 无缝钢管的尺寸范围及常用系列 /221
附录 5 螺栓、螺母材料组合及适用温度范围 /222
附录 6 钢板、钢管、锻件和螺栓的许用应力 /223
附录 7 平盖结构特征系数 *K* 选择表 /234
附录 8 图 5.6、图 5.8～图 5.16 的曲线数据表(GB 150.3—2011) /238
附录 9 压力容器用钢制法兰 /245
附录 10 钢制管法兰标准(HG/T 20592—2009) /252
附录 11 鞍式支座标准(JB/T 4712.1—2007) /272
附录 12 耳式支座标准(JB/T 4712.3—2007) /283
附录 13 裙座参数 /285

References 参考文献 …… 289

Ⅰ Materials of Chemical Equipment 化工设备材料

Chapter 1 Materials of Chemical Equipment and Selection 化工设备材料及其选择

1.1 General 概 述

Chemical industry is a fundamental industry. There are many different types of chemical equipments to meet the various needs of chemical production. The operating conditions of chemical equipments are relatively complicated. According to the operating pressure, the chemical equipments can be classified into vacuum, normal pressure, low-pressure, medium pressure, high pressure and ultra-high pressure vessel. According to the operating temperature, the chemical equipments also can be classified into low-temperature, normal temperature, medium temperature, high temperature pressure vessel. The characteristics of most media in chemical process are corrosive, flammable, explosive, toxic, poisonous and so on. Sometimes, the chemical equipment has to meet the specific requirements on temperature, pressure and corrosion-resistance. These above requirements occasionally conflict with each other and certain conditions change constantly.

The operational diversity makes the selection of appropriate materials for chemical equipment more complicated, which is an important part in designing of chemical equipment. The selection process must be based on the characteristics of different materials and their applications. The principles of application, safety and economy should be followed when selecting materials for chemical equipment.

The general requirements for the selection of chemical equipment materials are:

a. Material should be consistent with the resources and supplement.

b. Material should be reliable, and its operational life span should be guaranteed.

c. Material should have sufficient strength, excellent plasticity, toughness and corrosion-resistant capability.

d. Material should be easy to be manufactured and processed with good welding performance.

e. Material should be economic.

1.2 Material Properties 材料的性能

Material properties are mechanical properties, physical properties, chemical properties and processing performance, etc..

1.2.1 Mechanical Properties 力学性能

Component parts will deform till to break when the load exceeds a certain limit. The performance of materials to resist external forces including deformation and resistance force is called mechanical properties. The material mechanical properties are evaluated with elasticity, plasticity, strength, hardness and toughness under external forces.

The deformation till to failure process of metallic materials under external forces can be divided into the following three stages:

a. Elastic deformation

b. Elastic-plastic deformation

c. Breakdown

Generally there are two forms of breakdown. *Brittle breakdown* means that no obvious plastic deformation occurs before breakdown, and *toughness breakdown* means that the breakdown is the final result of accumulated extensive plastic deformation.

1. Strength

Strength is a characteristic of solid material resisting the plastic deformation and fracture under the external forces. The yielding strength and ultimate strength are generally as strength indexes.

(1) Yielding point (R_{eL})

The phenomenon that the obvious plastic deformation is still existed even the loading stops increasing or increases very slowly is called "yielding". The stress when the metal starts to yield and the plastic deformation occurs is called "yielding point" indicated by R_{eL} (MPa). The yielding point represents the capacity of materials to resist plastic deformation.

$$R_{eL}=\frac{F_s}{S_0} \tag{1.1}$$

where F_s is the minimum load which makes the test piece still continue to stretch when the load does not increase or even decrease, N; S_0 is the cross-sectional area of the test piece, mm^2.

In addition, most metal alloys have no clear yielding point except some annealing or hot-rolled low carbon steels and a few other alloys. Therefore, the stress under the residual elongation of 0.2% is called "conditional yielding point" expressed by $R_{p0.2}$ (MPa).

$$R_{p0.2}=\frac{F_{0.2}}{S_0} \tag{1.2}$$

where $F_{0.2}$ is the load generating the residual elongation of 0.2%, N.

R_{eL} and $R_{p0.2}$ are two important mechanical properties in the evaluation of engineering materials.

(2) Ultimate strength (R_m)

The maximum stress value when metal material is tensioned to ultimate breakdown is called the ultimate strength indicated by R_m (MPa). Ultimate strength is commonly used in pressure vessel design as a performance index. It is the maximum stress before the test piece being tensioned to breakdown.

$$R_m=\frac{F_m}{S_0} \tag{1.3}$$

where F_m is maximum load before the test piece being tensioned to breakdown, N.

R_m is used as an important mechanical property for engineering materials. Metallic materials used in engineering are not only expected to have an excellent R_{eL} but also required to have an appropriate ratio of yielding point to ultimate strength (R_{eL}/R_m). The smaller the ratio is the more plastic reservation of material will be. And the materials are less liable to the brittle failure. However, if the ratio index is too low the strength capability of the material cannot be fully exerted. On the contrary, the larger ratio makes the strength of the material be fully used and limited plasticity reserve. In engineering practice, the higher ratio is still expected .

(3) Creep strength (R_n^t)

The yielding point, ultimate strength, plasticity, elastic modulus and other properties of materials will change significantly under high temperature. Usually, with the temperature increasing, the strength and plasticity tend to increase and decrease respectively. Furthermore, the metal materials under high temperature have another important characteristics called "creep". The creep phenomenon refers that under a high temperature and a certain stress the strain increases as time goes by. In another word, the metal performs plastic deformation gradually under high temperature and inner stress.

Creep occurs even at room temperature for certain metals such as lead and tin. While for iron, steel and many non-ferrous metals the phenomenon of creep only appears when the temperature exceeds a certain value. For example, creep occurs only when the temperature reaches 350～400 ℃ for carbon steel and ordinary low alloy steel, 450 ℃ for the low alloy Cr-Mo steel and 550 ℃ for high-alloy steel. For light-alloy steel the creep occurs just when the temperature is higher than 50～150 ℃.

It is not rare that metal materials are damaged due to creep in practical engineering production. For example, the diameter of steam pipes at high temperature and high pressure will increase gradually as time goes by due to creep, which lead to the thickness of pipe and decreased pipe broken ultimately.

The ability of material at high temperature conditions resisting to slowly plastic deformation is called creep limit indicated by R_n^t(MPa). There are two definitions of creep limit:

a. The stress causing the specified deformation speed under operating temperature [$v=1\times10^{-5}$ mm/(mm · h) or $v=1\times10^{-4}$ mm/(mm · h)] ;

b. The stress causing specified total deformation within certain period and operating temperature.

For example, at a certain temperature, the maximum stress causing the total deformation of 1% within the 10000 hours or 100000 hours.

Material creep strength is related to the temperature and the speed of the creep. Table 1. 1 illustrates the creep limit of acid-resistant stainless steel (S32168) at a variety of temperatures and different speeds of creep.

Table 1. 1 Creep limit of S32168

Creep velocity mm/(mm · h)	The creep limit/MPa			
	425 ℃	475 ℃	520 ℃	560 ℃
10^{-6}	176	91	33	6
10^{-7}	—	88	19	—

(4)Creep rupture strength (R_D^t)

At a given temperature, the stress which causes the test piece to break with time is called the creep rupture strength expressed by R_D^t(MPa). Generally speaking, the life span of steels applied in the chemical vessels is designed to 100000 h and the stress under which the piece breaks at 100000 h is expressed as R_D^t.

Creep rupture strength is the capability of the material to resist tensile loading under a certain temperature. Considering the same conditions, the material which lasts longer has the greater ability to resist creep rupture.

(5)Fatigue strength (σ_{-1})

Many components and parts are often alternatively loaded both in quantity and dimension. The alternative load leads to the metal material breakdown at the stress level even far less than the yielding point. This phenomenon is called "fatigue". The maximum alternative stress not causing fatigue breakdown after innumerous alternative load test is defined as "fatigue limit".

In fact, it is impossible to do innumerous experiments, therefore the maximum stress not causing fatigue breakdown after $10^6 \sim 10^8$ alternative cycle tests is used as fatigue limit or fatigue strength. For example, bending fatigue strength(σ_{-1}, MPa) is defined as the maximum strength which will not cause fatigue breakdown after 5×10^6 alternative pure bending cycles. The bending fatigue strength of steel is usually equal to or less than the half of the ultimate strength.

The fatigue characteristics of material are affected by many parameters such as alloy composition, surface condition, organizational structure, the amount and distribution of impurities and stress concentration and so on.

2. Plasticity

Plasticity is an irreversible permanent deformation occurred before ultimate breakdown of material. The usual indexes of plasticity are percentage elongation(A) and sectional shrinkage rate (Z).

(1) Percentage elongation (A)

The percentage ratio of the total elongation length to original length of piece is called percentage elongation rate expressed by $A(\%)$ when the test piece is tensioned until breakdown.

$$A=\frac{l_u-l_0}{l_0}\times 100\% \tag{1.4}$$

where l_u is the length of test piece after deformation, mm; l_0 is the original length of test piece, mm; (l_u-l_0) is the absolute elongation of piece when break which is the plastic deformation of test piece from beginning to breakdown.

The value of A is related with the format of test piece.

(2) Shrinkage of sectional area (Z)

The ratio of the decreased cross-sectional area to the original one of a test piece when the piece breaks is defined as shrinkage of sectional area expressed by $Z(\%)$.

$$Z=\frac{S_0-S_u}{S_0}\times 100\% \tag{1.5}$$

where S_u is the minimum cross-sectional area of test piece after break, mm^2; S_0 is the original cross-sectional area of piece, mm^2.

The sectional shrinkage rate is not affected by the test piece size which means it is more reliable and sensitive to plasticity of materials.

Both percentage elongation rate and sectional shrinkage rate are often used to evaluate the metal plasticity. The larger parameters illustrate the better plasticity of metal materials. The sectional shrinkage rate of pure iron is almost 50%, and that of the ordinary cast iron is less than 1%. The plasticity of pure iron is far better than that of cast iron.

(3) Cold bending

Cold bending is also one of the index of plasticity for metal materials and welds. The cold bending property could be measured by the cold bending test. Metallic materials and welded joints at room temperature are bended with a certain radius. The larger deformation of bended test piece before the first crack appears means the better plasticity. Welded joint in bending test is evaluated by whether cracks appear with standardized certain bending angle($\alpha=120°$ or $180°$).

Cold bending test is an inspection not only for the pressure vessels but also for the welding test plate and the production plate. (It is cold bending rather than impact test is compulsory for the stainless steel.)

The plasticity index in engineering technology has important practical significance. Firstly, good plasticity is the basis for the molding process smoothly, such as bending, forging, stamping, welding, etc.. Secondly, the perfect plasticity prevents the parts from sudden breakdown caused by plastic deformation. Therefore, the pressure vessel and parts in static load require a certain degree of plasticity. However, the strength of material will decrease if the plasticity is too high, which is disadvantage to the pressure vessel.

3. Hardness

The hardness is the capacity of the resistance to deformation or rupture when a hard object is pressed into surface. It is known as the ability of material to resist the local deformation, indentation or scratch under the external force. Hardness illustrates whether the material is soft or hard. Hardness is not a simple physical index but rather an overall performance index comprehended with elasticity, strength, plasticity and stiffness of material.

The hardness of material is commonly measured by putting certain pressure head into metal surface, and then to measure the area or depth of the indentation. Under the constant pressure head, the larger or deeper indentation area means the lower hardness of material. According to the different pressure head and pressure, there are three types of hardness indexes: Brinell hardness (HB), Rockwell hardness (HR) and Vickers hardness (HV).

The measurement of Brinell hardness is to press a steel ball with diameter(D) into metal surface with loading(F) as shown in Figure 1.1. During holding time with the provisions of unloading, according to the indentation diameter d on test piece surface, brinell hardness of materials can be calculated with Formula (1.6). In the experiment, if the material hardness is no more than 450, steel ball indenter shall be used and the Brinell hardness is expressed by HBS. If the brinell hardness of material hardness is higher than 450 and no more than 600, carbide ball pressure head shall be used the Brinell hardness is expressed by HBW. If hardness is higher than 650 HBW, the measurement is inaccurate and Rockwell hardness measurement shall be used at that time.

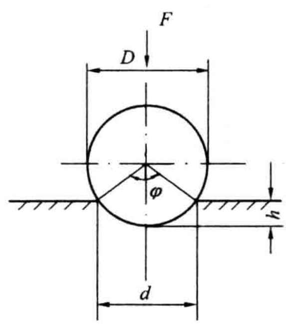

Figure 1.1 Brinell hardness experiment

$$\text{HBS(or HBW)} = 0.102\frac{F}{A} = 0.102\frac{2F}{\pi D(D-\sqrt{D^2-d^2})} \tag{1.6}$$

where F is loading, N; D is ball diameter, mm, the relationship between F and indenter diameter D in experiment is $F/D^2=0.102$; A is indentation surface area, $A=\frac{1}{2}\pi D(D-\sqrt{D^2-d^2})$, mm^2; d is indentation diameter, mm.

Brinell hardness is very accurate and is used wildly. But it can not test metals with great hardness, like HBW>650, and can not test the test pieces which are too thin. Moreover, because its indentation is too large, it is very liable to damage the surface of test piece.

Material hardness is one of the important performance indexes. Generally, high hardness leads to high strength and good resistance to wear and tear. For most metals, there is a certain relationship between hardness and strength. Therefore, the hardness can be used to estimate the ultimate strength. Based on experience, their relationship is approximately as follows:

For carbon steel, HBS≤140, $R_m \approx (3.68 \sim 3.76)$HBS; When 140≤HBS≤450,