Nuclear Science
2023; 8(1): 1-7
http://www.sciencepublishinggroup.com/j/ns
doi: 10.11648/j.ns.20230801.11
ISSN: 2640-4338 (Print); ISSN: 2640-4346 (Online)

Reunderstand and Discuss the Hardness Limits of RCC-M M5110 Part Materials

Shen Yu-sheng*, Li Fang-zhong, Ma Wen-sheng, Zhou Jie, Zhao Xing-ying, Yan Li-jun

Chongqing Pump Industry Co, Ltd., Chongqing, China

Email address:
cqsys1949@126.com (Shen Yu-sheng)

*Corresponding author

To cite this article:
Shen Yu-sheng, Li Fang-zhong, Ma Wen-sheng, Zhou Jie, Zhao Xing-ying, Yan Li-jun. Reunderstand and Discuss the Hardness Limits of RCC-M M5110 Part Materials. *Nuclear Science*. Vol. 8, No. 1, 2023, pp. 1-7. doi: 10.11648/j.ns.20230801.11

Received: February 23, 2023; **Accepted**: March 16, 2023; **Published**: March 24, 2023

Abstract: RCC-M M5110 is the procurement code for rolling or forging bars for bolts and drive rods of class 1, 2 and 3 equipment of nuclear power plants. The individual high strength steels involved in this specification specify only the minimum hardness of the material and have no limit on the maximum hardness. The material selection of major components of nuclear power machinery equipment must meet the requirements of load bearing and safe operation, and ensure sufficient strength and hardness, which is especially important for the material selection of connecting bolts and driving rods of nuclear power equipment. As the strength and hardness of high strength steel increase, the plasticity and toughness of materials decrease sharply, as do the mechanical properties and corrosion resistance, increasing the risk of bolt fracture and equipment damage. In order to ensure the strength and hardness of metal materials, it is necessary to consider the comprehensive mechanical properties and corrosion resistance of the material, including resistance stress corrosion cracking (SCC). Improving strength and hardness should not be the only goal of improving the performance of metal materials. In the formulation and selection of raw material standards, the mechanical properties of important equipment materials, such as hardness, must be limited. To meet the requirements of "redundant design" and "defense in depth" of nuclear power equipment. This paper will discuss how to reunderstand the the hardness limits of RCC-M M 5110 materials.

Keywords: RCC-M M5110, SCC, Bolt, Drive Rods, High Strength Steel, Hardness Limit

1. Introduction

France RCC-M M5110 [1, 2] covers the procurement of rolled or forged bars for the manufacture of class 1, 2 and 3 bolts and drive rods not covered by a specific procurement specification. These bolts and drive rods are used for PWR nuclear power equipment. The materials in the specification include not only some carbon steel and alloy steel, but also a variety of high strength stainless steel such as precipitated hardened stainless steel. Level 1, 2 and 3 equipment bolts involve the connection of bearing parts, and the driving rod is a moving force part. The importance of the materials used in these parts is closely related to the safety guarantee. Corrosion is the natural enemy of industrial equipment, as well as nuclear power equipment. In various corrosion forms, stress corrosion cracking (SCC) caused by the synergistic action of stress and environmental corrosive media has been concerned for a long time and is considered as the most dangerous corrosion form in various corrosion failures [3]. H_2S relates to sulfide stress cracking (SSC) of metal components, which is the most typical case in SCC. SSC has the overlapping effect of SCC and hydrogen emplacement, and H_2S itself is highly toxic, therefore, some domestic and foreign standards, involving H_2S medium equipment component material are very important. The American Petroleum Institute [4] requires that a pump component (including pump shaft and connecting bolt) exposed in wet H_2S be made of a material that reduces hardness according to the National Institute of Corrosion Engineers (NACE) MR0103 [5] or ISO15156-1 (ANSI/NACE MR0175) [6] standard. If an iron-based material other than that specified in the standard is selected, the yield strength of the material used shall not exceed 620N/mm² and the hardness shall not exceed HRC22. There seems to be little connection between the use of nuclear power plants and the environmental conditions containing liquid H_2S. But it should be noted that nuclear power equipment is also involved in a variety of corrosion and radiation, SCC also happens from time to time, which is even more dangerous. NACE is the most effective method and means to solve and prevent SCC for metal components exposed in wet H_2S gas, especially the material selection of bolts and drive rods. Nace requires to use the accumulated experience of experiments and field use to provide the maximum hardness limit and select materials with reduced hardness, as well as specified material selection requirements and principles. There are important reference value and some worthy of reference. The hardness of some materials in RCC-M M5110, especially the hardness of some high-strength steel used for bolts and drive rods, not only does not have the maximum limit, but also has a certain gap with the material selection principles and regulations of NACE, which is worth discussing. It is necessary to reunderstand and discuss the material hardness limits of RCC-M M5110.

2. Why Is It Necessary to Limit the Material Hardness of Bolts and Drive Rod Made of High Strength Steel

2.1. Limiting Hardness Is the Most Effective Method and Means to Prevent Bolts and Driving Rods Made of High Strength Steel from Being Damaged by SCC

There are three basic criteria [7] for the occurrence of SCC: First, there must be stresses (including applied loads and/or residual internal stresses), especially the presence of tensile stress components. The stress required for fracture is generally lower than the yield strength of the material. Two is the corrosion medium is specific, only some metal - medium combination (such as high strength steel and rainwater or seawater or H_2S aqueous solution combination) will occur SCC, and the rate of corrosion is generally small, corrosion is only the incentive; Third, the fracture is brittle. One of the important mechanisms of SCC is hydrogen embrittlement mechanism, which acknowledges that SCC has corrosion in the first place, and hydrogen embrittlement caused by hydrogen entering metal is the main cause of SCC. Both basic judgment and hydrogen embrittlement mechanism indicate that SCC is related to embrittlement of metal materials. Embrittlement reduces the plasticity and toughness of the metal, while tensile stress increases the sensitivity of the crack. In the early stage of global petroleum development in the early 20th century, a large number of equipment components of oil and gas fields suddenly broke, as well as a few years ago in China's nuclear power plant, the rupture of the connection bolts of pressure equipment, etc., all have a history of cracking caused by hydrogen. High strength steel, such as 17-4PH precipitation hardened stainless steel (corresponding to RCC-M M5110 grade: X6 CrNiCu17-04; American steel grade: 630; China Steel brand: 05Cr17Ni4Cu4Nb) [8] is the most sensitive material to hydrogen embrittlement, Table 1 shows its test data in H_2S environment [9]. The 686MPa tensile stress applied in the test is less than the yield strength of the sample. After solution treatment at 1040°C and aging treatment at 482°C, the hardness of 17-4PH precipitation-hardened stainless steel reaches HRC45, and the specimen breaks. However, no fracture occurs when the hardness is HRC35 and the aging temperature is 593°C. Experiments show that SSC can be avoided completely as long as precipitation hardened stainless steel is properly aged and the key is to obtain appropriate hardness. The yield strength of materials is often used as the standard in the design and analysis of stress in the selection of components, while the hardness used in the test is because the hardness has a certain relationship with the yield strength. Moreover, it is relatively easy to obtain hardness without cutting and making specimens. Based on this, NACE determined that there is a threshold of hardness for each metal that is exposed to a wet H_2S gas medium through external stress and various environmental tests. It is the most effective method to limit the hardness of materials to prevent metal components, especially those made of high strength steel, from being damaged by SCC. The Chinese oil industry recommended H_2S steel tubes used in oil and gas fields, requiring a hardness of less than HRC22, and achieved excellent results.

Table 1. *Hydrogen embrittlement test data of 17-4PH precipitation-hardened stainless steel.*

Aging temperature (°C)	**317**	**482**	**510**	**540**	**565**	**593**
Test piece	Complete rupture	break1 break2	No break	No break	No break	No break
Test time (d)	1~2	2 50	50	50	50	50
Test environment: 0.5%HAc aqueous solution containing saturated H_2S. sample: After solution treatment at 1040°C and aging treatment, each group had 3 samples. Tensile stress: 686MPa.						

2.2. Hidden Dangers Will Exist If the Hardness of Bolt and Drive Rod Members Made of High Strength Steel Is Not Limited

High-strength steel is mainly through alloying, plastic deformation and heat treatment, so that the composition and structure of the metal material itself have corresponding changes, there are certain side effects. For example, a high-strength steel reinforced by a solid-phase solution will highly deform the metal lattice, thus increasing the lattice strain, reducing its plasticity and toughness, and eventually leading to embrittlement. The reason why domestic and foreign standards attach great importance to the transmission of H_2S medium pump component selection, not sulfide corrosion is more serious, but the corrosion of hydrogen atoms more easily immersed, especially will promote the high strength steel metal lattice to produce greater deformation, not only reduce the plasticity and toughness of metal materials, but also accelerate embrittleness, and hydrogen embrittleness. Nuclear power equipment generally does not transport H_2S medium, but needs to transport seawater, high-temperature boron-containing water and chemical water related to three wastes. There is also the possibility of hydrogen involved in equipment manufacturing, such as material smelting, welding and pickling may have the presence of residual hydrogen. A few years ago, a bolt made of 17-4 PH precipitated hardened stainless steel for a nuclear power project broke, and it was later detected that the bolt material contained about 1ppm of hydrogen from the pickling process. Trace hydrogen does have great damage, but if you investigate deeply, the fracture of the bolt should have a great relationship with the hardness of the material. The bolt is made according to the RCC-M M5110 specification and tested. According to the specification of RCC-M M5110, the hardness of 17-4PH precipitation-hardened stainless steel bolts is not less than HRC32. API610/ISO13709 requirements, even if there is a trace H_2S, must choose to reduce the hardness of the material. The literature providing the test data in Table 1 indicates that the maximum hardness of 17-4 PH precipitated hardened stainless steel resistant to SSC can not exceed HRC 35, while NACE stipulates that the connecting bolts of pressure parts should not exceed HRC 29. Although these requirements are for H_2S, they are actually for hydrogen brittlement. The measured hardness of the broken bolt is HRC 35, reaching the test critical value, exceeding the limit value specified by NACE. The RCC-M M5110 specification also brings a problem, because there is no upper hardness value limit, the tracking professional fastener factory found that in order to meet the hardness requirements, plus the heat treatment aging temperature allows ± 10°C deviation, the different batches of 17-4 PH precipitation hardened stainless steel M24 bolts, measured hardness value above HRC 33. The highest level has reached HRC 38. The shock absorption energy A_{kv} (0°C) of the HRC 33 sample is 143J, and the HRC 38 sample is 74J, almost half the difference. This indicates that the ductility and toughness of metal materials decrease with increasing hardness. A careful study of ISO15156-1 / ANSI / NACE MR0175 and NACEMR 0103 standards shows that the selection of SSC components in H_2S environment is not that the materials with yield strength of more than 620 N/mm^2 and hardness more than HRC 22 cannot be selected. There are many iron-based materials with hardness more than HRC 22 in NACE MR0103, including 17-4 PH precipitated hardened stainless steel. What NACE has been trying to find is a threshold value for the hardness of various metals used in different environments, and then use that as a standard for the use of metals. NACE emphasizes the use of materials with reduced hardness, which means that the hardness of the materials used must be limited. Metal materials, especially high-strength steel, often involve fasteners and driving rods (including pump shafts) of important equipment. In addition, high-strength steel is more sensitive to embrittlement, and hardness must be limited. The above cases of bolt breakage and the facts of fastener manufacturers show that there will be hidden dangers in the materials of bolt and drive rod members made of high strength steel without limited hardness.

3. Reunderstanding and Discussion of Hardness Limits for Some Materials of RCC-M M5110

3.1. The Mechanical Properties of Bolt and Drive Rod Materials Should Be Different from General Rolling NEand Forging Raw Materials, and Can't Copy

There are generally two kinds of raw material standards. One is the material standard for final parts, such as: RCC-M M5110, which is very clear. It is the rolled or forged bar specification for 1, 2, 3 level equipment bolts and driving rod members. The other is the initial raw material standard, such as ASTM/ASME SA-705/SA-705M Specification for precipitate-hardened stainless steel forgings in ASME B&PV-II [10]. Bolt and drive rod parts, the purpose of use and required performance levels have been finalized, this kind of material standards need to provide information about its use. And the general rolling or forging of the initial profile, its final use goal is not determined, so it needs to provide information about its selection. The design and selection of components need to know the effective stress value of materials, and the yield strength of materials is generally used as the standard in the design and analysis of stress of component materials. Therefore, whether it is the use of information or the selection of information, it is necessary to know the minimum tensile strength value and the minimum yield strength value of the materials used and selected materials, in order to make a correct judgment on the calculation and selection of components. And the material hardness requirements, general raw materials and final parts of the material standards should be different. This is because the minimum value cannot be specified only for parts and components whose purpose of use and performance grade have been finalized, especially for bolts and driving rods. The connecting bolt of the pressure parts needs to bear the tensile load, while the driving rod part needs to bear the combined load of bending and torsion, and all of them are affected by variable working conditions. Bolts and nuts or threaded holes, need to be anti-bite; Driving rod parts such as pump shaft need to limit deflection deformation, which requires higher hardness of material. But the hardness is too high, the toughness is reduced, the impact capacity is reduced, there is a risk of fracture l, will affect its service life. Therefore, when a minimum value is specified, it is necessary to specify a maximum value for the hardness of the final component material. General raw materials, its final use needs to be selected, its hardness needs to be determined according to the requirements of the final use of parts, so the general raw material standards only stipulate its minimum hardness value. Some standards at home and abroad follow this principle, with different restrictions on raw material standards for general raw materials and final components. Such as: ASME/ASTM SA-193/SA-193M [11] high temperature and high pressure and other special purpose alloy and stainless steel bolts, ASME SA354 [12] tempered alloy steel bolts and other external thread fasteners, China GB/T3098.1 [13] fasteners mechanical properties bolts, screws and bolts. There are minimum and maximum hardness values for each specification or grade of bolt material. In other words, there are maximum value limits. as detailed in Table 2. However, some general raw material standards give only the lowest hardness values, such as ASME/ASTM SA-705/SA-705M [14] precipitate-hardened Stainless Steel forgings specifications, as detailed in Table 3. Because the hardness of metal materials is closely related to the conditions and states of heat treatment, the specification also recommends a variety of heat treatment conditions for selection of final parts. For bolt and drive rod parts, although the heat treatment conditions have been selected and specified for RCC-M M5110, there is no limit to the maximum hardness value for some materials. as detailed in Table 4. For the hardness values, also need to be based on the performance and use of parts to make choices and limits, rather than the raw material standards simply transplanted and copied.

Table 2. *Hardness Requirements For Full-Size Fasteners [12].*

Size In.	Grade	Hardness			
		Brinell		Rockwell C	
		Min.	Max.	Min.	Max.
¼ to 2½	BC	255	331	26	36
Over 2½	BC	235	311	22	33
¼ to 2½	BD	311	363	33	39
Over 2½	BD	293	363	31	39

Note: The above is taken from: ASME SA354 Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners TABLE2

Table 3. *Type 630 Mechanical test requirements after age hardening heat treatment [14].*

Typr		Suggested Hardening or Aging Treatment, Or both B, C, D			Applicable thickness, in and Test Direction E	Tensile strength	Yield strength	Elongation in 2 in. [50mm] or4D	Reduction of Area,	Hardness G		Impact Charpy-V,	
						min	min F	min	min	min		min	
	Condition	Temperature °F [°C]	Time h	Quench		Ksi [MPa]	Ksi [MPa]	%	%	Rockwell C	Brinell	Ft-lbf	J
630	H900	900 [480]	1.0	Air cool	≤ 3 in. [75mm] (L)	190 [1310]	170 [1170]	10	40	40	388	…	…
					> 3 in. [75mm] ~ 8 in. [200mm] (L)				35				
	H925	925 [495]	4.0	Air cool	≤ 3 in. [75mm] (L)	170 [1170]	155 [1070]	10	44	38	375	5	6.8
					> 3 in. [75mm] ~ 8 in. [200mm] (L)				38				
	H1025	1025 [550]	4.0	Air cool		155 [1070]	145 [1000]	12	45	35	331	15	20
	H1075	1075 [580]	4.0	Air cool	≤ 8 in. [200mm] (L)	145 [1000]	125 [860]	13	45	32	311	20	27
	H1100	1100 [595]	4.0	Air cool		140 [965]	75 [520]	14	45	31	302	25	34
	H1150	1150 [620]	4.0	Air cool		135 [930]	105 [725]	16	50	28	277	30	41
	H1150M	1400 [760] for 2 h, air cool plus 1150 [620] for 4.h, air cool				115 [795]	75 [520]	18	55	24	255	55	75

…

B: Time refers to minimum time material is at temperature and may be extended to obtain required ductility. properties.

C: Unless otherwise noted, temperatures shown are suggested temperatures and may be varied to obtain required tensile properties.

D: Intermediate temperature must meet the ductility requirements of the next highest suggested hardening or aging temperature, or both. Example: Type 630 at 1050°F [565°C] must have 13% elongation and 45% reduction, same as for age hardening at 1075°F [580°C].

E: (L)— Longitudinal axis of specimen is parallel to direction of grain flow during rolling or forging; (T)—Transverse axis of specimen perpendicular to direction of grain flow during rolling or forging.

F: See 6.2

G: Either Both Rockwell C and Brinell is permissible. On sizes 1/2in (12.70mm) and smaller. Rockwell C is preferred

Note: The above is taken from:: ASME/ASTM SA-705/SA-705M Specification for age-hardening stainless steel forgings TABLE3.

***Table 4.** Mechanical properties common to X6 CrNiCu 17-04 X6 CrNiCuMo 15-04 [2].*

NAME OF TEST	TEST TEMPERATURE	PROPERTIES		REQUIRED VALUE dia ≤ 200			
				AFTER IMMER-SION IN SOLU-TION(3)	After age hardening treatment		
					Bolting materia	Valve rods	
					Grade A	Grade A	Grade B
Tension	20	$R_{p0.2}$ minimum value			790 MPa	790 MPa	720 MPa
		R_m minimum value			960MPa	960 MPa	930 MPa
		A % (5d)minimum value			14	14	16
		Z % minimum value (1)			45	35	35
	350°C	$R^t_{p0.2}$ minimum value			630 MPa	630 MPa	580 MPa
KV impact (1)	0°C	Minimum average value Lateral expansion			60J ≥ 0.64mm	60J	60J
KV impact (2)	0°C	Minimum average value			40J	40J	40J
Rockwell hardness	20	dia. < 10mm	max. value	38 HRC	-	-	-
			min. Individual value	-	32 HRC	32 HRC	28 HRC
Brinell hardness	20	dia. ≥ 10mm	max. value	363 HB	-	-	-
			min. Individual value	-	302 HB	302 HB	277 HB

(1) Class 1 bars
(2) Class 2 and 3 bars
(3) For bars delivered in the solution heat treated condition.

Note: The above is taken from the RCC-M M5110 ROLLED OR FORGED BARS FOR THE MANUFACTURE OF CLASS 1, 2 AND 3 BOLTS AND DRIVE RODS ANNEX VIII

3.2. Increasing Strength and Hardness Should Not Be the Only Purpose and the Only Option to Improve the Performance of Metal Materials

Research determined the protection method of SCC/SSC based on hydrogen embrittlement mechanism, which is different from the corrosion of acid media on the surface of metal materials, the pitting corrosion of seawater and chloride on metal materials including crevice corrosion and intergranular corrosion of metal materials. The influence of corrosion margin of metal surface, pitting resistance index (PRE) of metal material and stabilizing elements of metal chemical composition is often ignored. For SCC, material embrittlement is the primary cause of increased fracture sensitivity of connecting bolts and pump shafts. The methods to prevent embrittlement are mainly related to the mechanical properties of materials. The increase of strength and hardness of metal materials should be limited, because increasing strength and hardness is not the only purpose and the only option to improve the performance of metal materials. For the application of metal materials, in addition to improving the strength and hardness, it is necessary to pay attention to the comprehensive properties of materials. In particular, it must be based on the conditions of use, requiring sufficient plasticity and toughness as well as adaptability to the environment and medium. With the increase of strength and hardness, the plasticity and toughness of the material will be reduced, and the mechanical properties and corrosion resistance will become worse. In fact, most iron-based alloys are irradiation-resistant, and austenitic stainless steel is widely used in nuclear power plants. First, it has a strong adaptability to many acidic media, especially boric acid, and second, its low hardness and high plasticity. RCC-M M5110 materials, not all of which have no hardness limits, the specification of alloy steel, martensitic stainless steel, non-work hardened austenitic stainless steel, and other materials, have specified minimum and maximum values of hardness. But highly sensitive to embrittlement of work hardened austenitic stainless steel and age hardened martensitic stainless steel, but only the minimum hardness of these materials, it is difficult to understand.

3.3. Many Provisions of NACE MR0103 Are Worth Learning from by RCC-M M5110

NACE MR0103 is a standard developed specifically for the selection of metals resistant to SSC cracking in petroleum refining environments. This standard is based on laboratory test results and field experience. On H_2S corrosion environment material selection, NACE MR0103 stipulates strict evaluation rules including test methods and material selection principles, provides a detailed material selection conditions and list, especially given in line with the standard material selection conditions and manufacturing process provisions of the "road map", a variety of iron base material and non-ferrous metal allowed chemical composition, thermal conditions and heat treatment conditions, As well as the manufacturing process conditions (including plugging, plating, welding, etc.) allowed in the application of these materials in products (such as compressors and pumps), the corresponding chapters and provisions of the standard are detailed, with strong pertinence and operability. Still take 17-4PH precipitation-hardened stainless steel as an example, "road map", the stainless steel adaptation clause is 13.9. In 13.9, it is specified that the highest hardness of forgings is HRC33 when used in the H_2S environment; The highest hardness of casting is HRC30; The maximum hardness of the connection bolt of the pressure component is HRC29. Among them, the forgings heat treatment regime must be carried out as 13.9.2.3 or 13.9.2.4, similar to the H1150 in Table 3 of this article, but in more detail. The corresponding heat treatment system is also stipulated for the connection bolts of castings and pressure parts, and the H1150 treatment of the connection bolts of pressure parts shall not be more than two times. Detailed regulations such as these cover almost all the materials listed in the "Road map" with specific heat treatment conditions and maximum hardness limits. The standard also has many unique measures to prevent the embrittlement tendency of metal materials. For example, not to improve the strength of mechanical properties for the purpose of cold hardening of austenitic stainless steel (including some materials can not be cold rolled profiles); It is not allowed to add selenium, lead, sulfur and other alloy elements in the material to improve the processing performance; The ferritic content of duplex stainless steel should be controlled within 35%~65%, and it is not allowed to aging treatment; The σ phase in ferritic stainless steel and duplex stainless steel should be limited rather than unconditionally reserved. NACE advocates that maximum hardness limit data should be provided by the summary of experience accumulated in experiments and field use, as well as various measures mentioned above to prevent the tendency of embrittleness of metal materials, as well as various methods of material evaluation and principles of material selection, which have strong persuasive and practical application value. Although SSC is a special case of SCC, as a response to prevent the occurrence of SCC, it has a good reference effect on the selection of metal components, especially the connection bolts of pressure parts and the driving rod members of nuclear power equipment, and it is worth using. It is almost impossible for nuclear power equipment to involve SSC, but SCC cannot be avoided. From the principle of "redundant design" and "defense in depth", it is necessary to prevent bolts and driving rod parts, including pump shaft. RCC-M M5110 not only does not have NACE MR0103 requirements, but instead allows the use of work-hardened austenitic stainless steel for bolt and drive rod types with no limit to the maximum hardness after hardening, nor to the hardness of martensitic precipitation-hardened stainless steel. This from another side reflects the shortcomings and problems of RCC-M M5110.

3.4. It Is Necessary to Re-understand and Discuss the Hardness Limits of RCC-M M5110 High Strength Steel

Because of France's achievements in the construction of pressurized water reactor nuclear power, as well as China's introduction of French nuclear power technology. The RCC-M specification, as the mechanical equipment design and construction of pressurized water reactor nuclear island, not only in nuclear power construction, but also in other engineering projects has a great impact on the Chinese engineering community. Based on ASME Volume B&PV-III [15], RCC-M inherits the essence of ASME through years of nuclear power construction practice, extensively drawing on French experience and technology in design, construction, operation and other aspects of nuclear island mechanical equipment for pressurized water reactor nuclear power units, and citing French, European and ISO standards. In addition, it has its own characteristics. It also reflects the technical level of the mechanical equipment of the nuclear island of the contemporary pressurized water reactor nuclear power plant, which has been recognized and applied by China's nuclear power industry. For some time, many Chinese companies have been using RCC-M M5110 as a basis for the preparation of technical requirements for the procurement of bolts and shafts for nuclear power and some important projects. Because 17-4PH precipitation hardened stainless steel has excellent corrosion resistance of austenitic chromium-nickel stainless steel and high strength of martensitic chromium steel, especially in the Chinese pump industry, it is not only used as a material for connecting bolts of pressure parts of nuclear power equipment, but also used for pump shaft production of important projects such as nuclear power, metallurgy, petrochemical and coal chemical industry. However, breakage of the bolt and pump shaft made of 17-4PH precipitation-hardened stainless steel often occurs [16], Most of these breaks are brittle breaks. Some enterprises in China only limit hydrogen and implement regulations when dealing with bolt breakage. As for hardness limits, they are not on the agenda. Related to the 17-4PH precipitation hardening stainless steel bolt and pump shaft material procurement technical conditions, but also retained only RCC-M M5110 hardness regulations. In addition, GB/T16907/ ISO9905 [17] and API610 still have contradictions [18] in the strength requirements of pump components exposed to wetH_2S gas, and lack corresponding understanding and discussion on the hardness limit, which needs to attract the attention of the industry. According to the use of 17-4PH precipitation-hardened stainless steel by many companies, there is a risk of breakage of the bar material after the hardness of this material exceeds HRC40. For rotating shaft and pressure connection bolt, the hardness of the material should be controlled within HRC28 ~ HRC32, and its maximum hardness should be limited within HRC33.

4. Conclusion

The material selection of major components of nuclear power machinery equipment must meet the requirements of load bearing and safe operation, and ensure sufficient strength and hardness, which is especially important for the material selection of connecting bolts and driving rods of nuclear power equipment. To ensure the strength and hardness of the material, it is necessary to consider the corrosion resistance of the material, including the SCC resistance. At the same time, again emphasize here: The materials used in nuclear power equipment need comprehensive mechanical properties and improving strength and hardness should not be the only purpose and option to improve the properties of metal materials. When formulating and selecting raw material standards, the material standards of important parts and the general material standard of rolling and forgings must be treated differently without simply copied; the mechanical performance indexes of important materials must have the threshold (such as the hardness of high strength steel mentioned in the article), and the threshold should be determined by test to avoid future problems. It is necessary to limit the hardness of high strength steel members, which is the requirement of "redundant design" and "defense in depth", and should become the principle of equipment materials in high-risk industries. The case studies presented here and the production and analysis of professional fasteners show that it is a realistic need to reunderstand and discuss the hardness limits of RCC-M M5110 high-strength steel and very necessary.

References

[1] RCC-M: Design and construction rules for mechanical components of nuclear island components French association for design, construction and in-service inspection rules for nuclear island components 2007.

[2] RCC-M M5110: RCC-M SECTION II MATERIALS 2007.

[3] ASTM-AIME, Symposium on Stress Corrosion cracking of Metals 1945.

[4] API 610: 2021/ISO13709: 2020 Centrifugal pumps for petroleum, petrochemical and natural gas industries.

[5] ANSI/NACE MR0103/ ISO17495-1: 2016 Petroleum, petrochemical and natural gas industries—Metallic materials resistant to sulfide stress cracking in corrosive petroleum refining environments.

[6] ANSI/NACE MR0175/ISO15156-1: 2015 Petroleum, petrochemical and natural gas industries—Materials for use in H_2S-containing environments in oil and gas production— Part 1: General principles for selection of cracking-resistant materials.

[7] Li Xiao-gang chief Editor Introduction Corrosion and Protection of Materials (Second Edition) CHINA MACHINE PRESS 2017.

[8] Ji Gui chief Editor World Steel Number Control Manual China Standards Press 2007.

[9] Araki Toru, et. Editor Iron steel corrosion science Japan, Asakura Bookstore 1972.

[10] ASME: 2021 Boiler & Pressure Vessel Code II Materials Part A- Ferrous Material Specifications.

[11] ASME/ASTM SA-193/SA-193M Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications 2021.

[12] ASME SA354 Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners 2021.

[13] Chinese national standard: GB/T3098.1-2010 Mechanical properties of fasteners- bolts, screws and studs.

[14] ASME/ASTM SA-705/SA-705M Specification for Age-Hardening Stainless Steel Forgings. 2021.

[15] ASME: 2021 Boiler & Pressure Vessel Code III Rules for Construction of Nuclear Facility Components.

[16] ZHANG Chen-li LI Jian-hua XU Liang Failure analysis of broken shaft of multistage centrifugal pump Petro-chemical Equipment 40 (3) 2019.

[17] GB/T16907-2014/ ISO9905 Technical specifications for centrifugal pumps - Class I.

[18] SHEN Yu-sheng LIU Yuan YAN Li-jun, How look at Exposed under Wet H_2S Gas the Difference of pump Parts Material Strength Limit Value between Two Standard (GB/T16907 and API610) Pump technology (1) 2020.