# History and future prospects of technologies and products of the Muroran Plant
## ― focusing on energy and preservation of environment ―

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―Synopsis―

Responding to the rapid growth of economy after World War II, many high quality and high reliability products have been supplied from the JSW Muroran Plant for many energy plants such as fossil and nuclear power and oil refinery. Recently, due to the protection of environment from global warning and conservation of natural resources, improvement of efficiency of energy plants, development and use of renewable energy, application of hydrogen energy and so on are stringent to be materialized. At present, to meet the request of industry, development of new materials and production technologies for high performance products have been continuously running in Muroran Plant. Production technologies of wind power system, which is typical renewable energy, has been established. Researches for advanced materials and systems are also continuing. Here, the history and prospects of material and production technologies of JSW Muroran Plant are described.

## 1. Introduction

After years of construction, Muroran Plant started production in 1911 as the Japan Steel Works' first mill. Since then, the plant has been cultivating its core technologies particularly in the range of manufacturing steel forgings, castings, and steel plates aiming to play a valuable part in the progress of Japan's heavy industrial sector as the manufacturer of largest steel components.

After World War II, the Mroran Plant swiftly converted its products to meet private-sector demands and has consistently met the needs from domestic and foreign customers by supplying forged and cast steel products, steel plates, pressure vessels for the chemical and petrochemical industries, and a wide range of industrial machinery during the latter half of 20th century. At the same time, the staff of Muroran Plant have been constantly devoting efforts to develop innovation on manufacturing and to accumulate technological know-how intending to produce the useful materials and components needed in the industrial society.

In the process mentioned above, recognizing both strength and weakness of own technologies, Muroran Plant has been gradually selecting its target areas. As a result of the preceding selection and concentration, strategic re-construction of business scope of Muroran Plant attempting business expansion in the direction of global energy industries has been progressing rapidly after entering the 21st century.

That is to say, predicting the increase of world energy demand or the change in demand structure, while striving to anticipate the global trend of energy development from the viewpoint of environment preservation, the Muroran Plant has settled its principal mission expressed by the following slogan "Technology and Products focusing on Energy and Preservation of Environment" as the main vector of activity looking out on the new century. At present, innovation of existing technologies for improvement of energy efficiency or conservation of natural resources, as well as R&D of new technologies for expansion of renewable energy use or development of zero-emission energy have been continuously and more strongly running in the plant, intending the evolution of its own to become a globally contributing manufacturer.

The above mentioned challenge or global activity of the plant is rooted in manufacturing large components responding to the demand of increase in capacity of turbines and reactor pressure vessels in fossil and nuclear power plant, or in oil refinery project from late 1960s. JSW Muroran Plant has been committed to be the leading manufacturer in

*Muroran Plant **Muroran Research Laboratory

developing big forgings made from large and ultra large ingots, such as mono-block turbine rotor shafts and transition cone shells fabricated in steam generator as the main unit in the nuclear power plant. These integrated components have been produced taking the lead to the world using advanced technologies in making high purity large ingots and in the forging process supported by core technologies in the Muroran Plant. And these integrated components, together with material improvements, contributed also to the improvement in reliability and durability of main units in the energy industrial plants, for example, by reducing the number of weld seams of welding fabricated constructions.

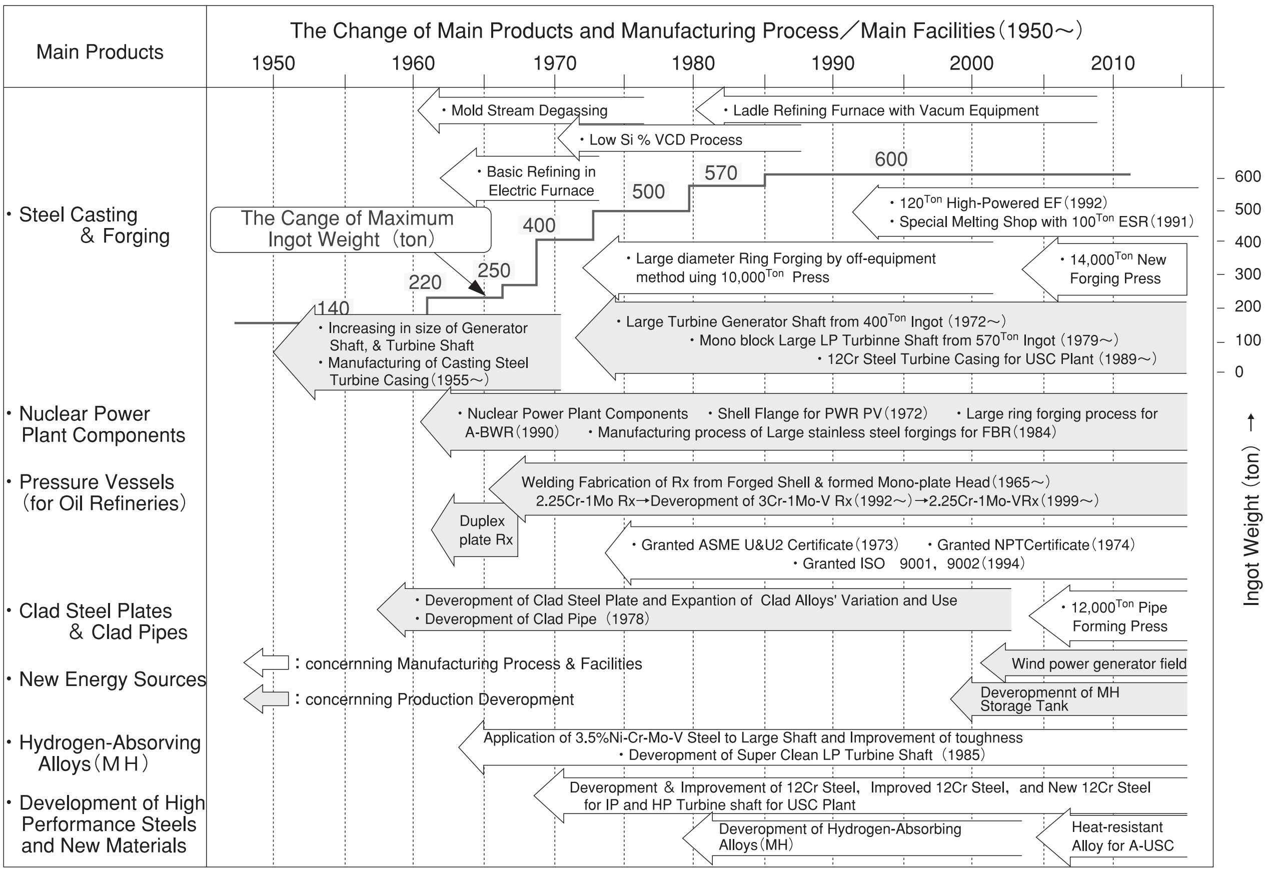
In addition to the above, JSW has consistently performed the research and development of turbine materials responding to requirement for elevation of steam temperature and improvement of efficiency of fossil power plants represented by USC plant, and taken the initiative in realizing the commercial components positioned as the best achievement of the era.

JSW clad steel plates have been widely used in many industrial fields such as construction of desalinations plants and building chemical tanker as a high performance material. In recent years, there has been a huge increase in demand for JSW clad steel pipes that were developed aiming at expansion of clad steel plates' usage. Because of the combination of corrosion resistance and mechanical properties obtained at relatively low cost, clad steel pipes enable to construct a long distance transport pipeline of natural sour gas economically, thus to support exploration of natural gas fields due to increasing demand for natural gas as an alternative energy source.

Responding to the expansionary policy of renewable energy use, approach to wind power generation business in Muroran Plant started with manufacturing the tower of the wind turbines as the first step in 2000. Now, JSW attempts the business expansion aiming to become a comprehensive manufacturer of the wind turbine by establishing wind power generation system that can cope with harsh meteorological conditions in Japan.

**Table 1** shows the historical improvement in the manufacturing technologies together with the change of maximum ingot size, main facilities, and main products.

Table 1 The Change of Main Products and Manufacturing Process, Main Facilities



In the following chapters, the history and the future prospect of technologies and products of the JSW Muroran Plant are introduced in detail referring to development of new materials looking forward as the basic technology of the plant, as well as touching on the technologies around hydrogen which is regarded to be the final zero-emission energy, and base technologies that promote the hydrogen energy society.

## 2. History of manufacturing of forged and cast steel products responding to the demand on improvement of efficiency and reliability in fossil and nuclear power plants

### *2.1 Forged steel products for energy industries*

#### *2.1.1 History of forgings production*

A century has passed since JSW started production of forgings. The approach for the current large forgings manufacture started with the installation of a 10,000 ton hydraulic press that began operation in February, 1940. Although the rotor shaft forging which is one of current main products had been manufactured during World War II, its fullscale production started in 1950s.

In those days improvement in living standards made energy shortage, the construction of thermal and hydro power plants has spread quickly over Japan just like current power generation boom in China. Along with this, current JSW has become a leading rotor shaft forging supplier.

Thermal power generation expanded matching with government's coal policy. However, issues of output and cost shifted coal as fuel from domestic coal to imports and heavy oil. On the other hand, construction of nuclear power plants in Japan began in 1960s in the peaceful use of nuclear energy. Based on the experience of the manufacture of forged rings for marine turbine, JSW came into production of forged rings for nuclear pressure vessel which has reliable and economical advantage compared to weld construction of steel plates. At that time, nuclear energy department as design and planning section of JSW was formed and manufacturing of forged products for nuclear pressure vessels started. Since then JSW has manufactured many forgings for nuclear power plants winning high trust from KWU, current Siemens in Germany as well as Japanese customers and established bases for the current success.

Then development of manufacturing technology and installation of new facilities were promoted in order to meet demands for integraded larger size forgings, (less weld seam), high purity, heat resistant and corrosion resistant due to the expansion of the unit capacity of power plants, elevation of steam temperature seeking for high efficiency and the sophisticate of safety and reliability. In 1960, installation of Bochumer-Verein stream degassing facility enabled removal of hydrogen from molten steel, melting process of acid open hearth furnace / basic electric furnace has been changed to basic open hearth furnace / basic electric furnace. In 1972 installed holding furnaces to produce large ingots, and open hearth furnace, was scrapped. Ladle refining furnaces was installed in 1980.

Thereafter, additionally installed ladle refining furnaces together with multi pouring technique which had been developed since 1960s for large ingot succeeded in producing 600 ton ingots of fully ladle refined steel. **Photo. 1** shows the appearance of 600 ton ingot. Other melting facilities such as electro slag remelting (ESR) and vacuum induction melting (VIM) were also installed. Especially ESR can produce 100 ton ingot that is the largest in Japan. As ingot making process, vacuum carbon deoxidization (VCD) technique industrialized in 1970 together with low silicon content improved solidification structure, reduced macro segregation of large ingot and contributed to reducing temper embrittlement susceptibility which had become major concern in equipments operated at high temperature.

Using three forging presses, 10,000 ton began operation in 1940, 8,000 ton installed in 1970 and 3,000 ton began operation in 1989, JSW has produced many large forgings and developed forging technique such as special forging process (JTS) and outside pressing. The 10,000 ton press was upgraded to 14,000 ton press in 2003. **Photo. 2** shows forging operation of 14,000 ton press.

Heat treatment furnaces for shaft forging with diameter up to 3 meters and forgings for nuclear pressure vessels with outer diameter exceeding 7 meters were installed, and heat treatment techniques such as micro structure refining of meterials and differential heat treatment were also established.

Many large NC lathes for the machining of large forgings were also installed. In addition, for the purpose of checking reliability of products, superior inspection technique and material evaluation systems such as fracture mechanics methodology were adopted quickly.

JSW has kept developing manufacturing

Photo. 1 Appearance of 600ton Ingot

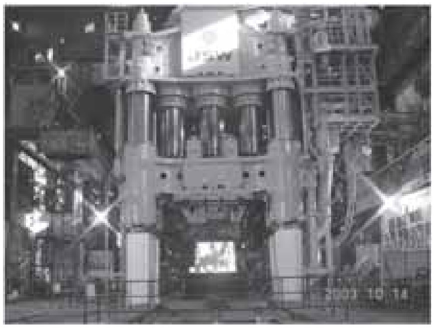


Photo. 2 Forging Operation of 14,000 ton Press

technology and supplying high quality products after WW II even experiencing some hard times due to bad business situation. Recently the life extension and uprate programs of nuclear power plants mainly in US and Europe have generated forgings' big demand for reactor pressure vessels, steam generators and turbine rotors. Also Chinese thermal power plant construction boom due to power shortage in rapid economic growth made big demand for rotor shaft forgings for 300 − 600MW.

With the movement for emphasizing global environment implementing the Kyoto Protocol to reduce $CO_2$ emission, thermal power plants are going forward to USC and large capacity. For environment-friendly nuclear power plants, projects for building new power plants are growing rapidly. Pursuing high security, the mainstream is third-generation reactors such as ABWR, ESBWR, EPR, AP1000 and APWR with output of 1,000 to 1,700MW that request ultra large forgings made from 350ton or 600 ton ingots. For the manufacture of monoblock LP turbine rotors for such large scale nuclear power plants, new design of large ingot that exceeds 600 tons should be considered.

JSW made large expansion of investment before beginning of WW II and now will make another short term heavy investment for supplying large quantities of ultra large forgings. At beginning of the second century of JSW, we position this investment as laying foundation for the challenge in the future energy field and put our energy in developing manufacturing technology of products for next generation plants such as advanced USC, fast-breeder reactor, fusion reactor and high temperature gas cool reactor.

*2.1.2 Rotor shaft forgings for power generation*

(1) Manufacturing technology of ultra large rotor shaft forgings

**Fig. 1** shows the transition of the maximum unit capacity of power plants and JSW's maximum ingot weight. JSW has been manufacturing rotor shaft forgings since the prewar period and its manufacturing technologies such as refining of steel, ingot making, forging and heat treatment have been drastically developed since late 1960s in order to respond to the demand of large rotor forgings due to the rapid increase of power generation capacity, afterward it has become able to manufacture ultra large rotor shaft forgings with high quality and high reliability from ultra large ingots. Vacuum Carbon Deoxidization (VCD) technique established in 1970 together with low silicon content enabled to improve solidification structure and reduce macro segregation of large ingot. JSW manufactured the world's largest 4-pole generator shafts by using 400 ton ingots followed by lager 4-pole generator shafts by using 500 ton ingots in 1972. With this manufacturing technologies of ultra large ingot, design of large turbine rotor with shrunk-on discs has been changed into "monoblock" and JSW succeeded the manufacture of large monoblock turbine rotor shaft forging for Germany in 1976 using 400 ton ingot. Since the first monoblock low pressure (LP) turbine rotor shaft forging for domestic 700 MW thermal power plant in 1979, JSW has manufactured monoblock LP turbine rotor shaft forgings for 1,000 MW nuclear power plant in 1980 using 570 ton ingot and 1,350 MW ABWR nuclear power plant in 1992 using 600 ton ingot. So far more than 200 large monoblock turbine rotor shaft forgings have been supplied to the world. (**Fig. 2**)

Outstanding technologies such as manufacturing technology of sound ultra large ingot, forging technology to secure internal soundness, heat treatment technology to achieve ultrasonic flaw detectability as well as high strength and high toughness throughout the large diameter up to 3 meters. Using multi-pouring process, number of ladle refined molten steel is poured into the mould under vacuum to be one ultra large ingot.[1] Hot working with 14,000 ton hydraulic forging press forms rotor shape, transforms the cast structure of ingot into the

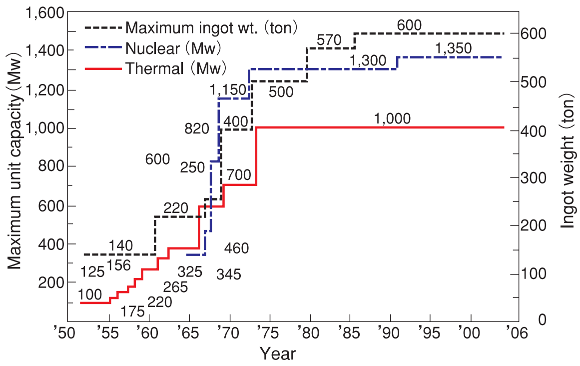



Fig. 1 Transition of the maximum capacity of power plants and ingot weight of JSW

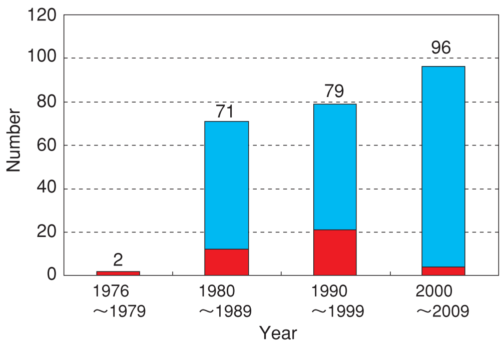



Fig. 2 Mnufacturing Number of Monoblock Turbine Rotor Shaft Forgings

forging structure and consolidates micro porosities. Multiple austenitizing makes fine grain structure and achieves good ultrasonica flaw detectability even for large monoblock turbine rotor shaft forging with diameter up to 3 meters and quality heat treatment using vertical round electric furnace gives the forging strength and toughness. **Photo. 3** shows ultra large monoblock turbine rotor shaft forging.

Photo. 3

(2) Super clean steel

It is of course important to reduce gasses and impurities such as hydrogen, oxygen, phosphorus, tin and copper that may cause defects and degradation of material during production or operation. In order to make clean steel ingots, JSW installed ladle refining furnaces in 1980 that can perform vacuum degassing and expanded its capacity in 1986 that enabled to produce 600 ton ingot with all ladle refined clean steel using 6 ladle refining furnaces. On the other hand, it was planned since 1980s to develop ultra super critical (USC) power plants to improve the efficiency of thermal power plants by increasing main steam temperature /pressure and reheat steam temperature. Also materials insusceptible to temper embrittlement were requested to apply to LP turbine rotor shafts for higher operating temperature. In order to restrain temper embrittlement susceptibility, super clean steel that had extremely-low J factor: (Si+Mn)(P+Sn) · $10^4$ (wt%) was necessary. After manufacturing prototype super clean forging in 1985 by using the latest ladle refining technology and careful selection of raw materials, JSW manufactured super clean LP turbine rotor shaft in 1987 for Japanese first USC 700MW thermal power plant. More than 70 super clean rotors including ultra large monoblock LP rotors have been supplied.[(4)]

(3) Response to high temperature applications and future outlook

High efficiency of power plant is going forward with building more advanced combined cycle (MACC) and USC power plants as a countermeasure to global environmental problems by $CO_2$ emission. JSW developed the materials and manufacturing technologies of monoblock HP-LP rotor shaft forgings[(5)] that combines HP/IP rotor shaft and LP rotor shaft into single shaft for combined cycle power plant. For further high steam temperature application, JSW also established the manufacturing technology of new 10-12%Cr rotor forgings[(6)] with improved creep strength by adding tungsten, cobalt and boron.[(7)] In recent years, USC and large-scale thermal power plants have been newly built mainly in China. The demand of 10-12%Cr rotor forgings for HP/IP turbines is increasing. And for higher steam temperature up to 650℃ application, the demand of above mentioned new 10-12%Cr rotor forgings is also increasing. JSW started development of 10-12%Cr rotor forgings collaborating with Japanese turbine OEMs from late 1960s. Since the first 10-12%Cr HIP turbine rotor forging for 375MW thermal power plant in 1971, more than 70 pieces of 10-12%Cr rotor forging have been supplied. In order to prevent galling damage on journal portion of 10-12%Cr rotor forgings, overlay welding technology instead of shrunk-on sleeve low Cr steel is already established[(8)]

On the other hand, nuclear power plant is recently re-evaluated as a countermeasure to global environmental problems and there are plans for building new plans such as EPR and APWR with further large capacity. JSW will go for stable and long-term supplying of ultra large rotor shaft forgings used for such large-scale power plants.

### *2.1.3 Nuclear Products*

(1) Increment of output capacity and requirements for materials

The steel plates manufactured in U.K. were rejected due to the defects at receiving inspection in Japan for the first commercial nuclear reactor Tokai#1 (Calder Hall Reactor). Replacement was manufactured in JSW. This was the first challenge to supply the materials to nuclear reactor by the Japanese.[8]

The capacity of nuclear power plant had been rapidly increased from 340 MWe in 1960s to 1,000 MWe in 1970s. Then, increased to 1,300 MWe, 1,600 MWe new plant is under construction.

Nuclear components have become to be larger and heavier with increment of output capacity of plant. In parallel, it has been strongly required 1) to improve safety and reliability, 2) to reduce cost and 3) to reduce construction period for material manufacturing, also. The rector pressure vessels were fabricated by welding of formed plates in the former time. The manufacturing technology of forged ring and heads was developed so that the vertical weld seams with high stress could be eliminated. As the results of using forgings, number of weld seams and parts could be reduced in components.

JSW continues to improve the technologies for 1) making of larger ingot, 2) to get higher cleanliness and fracture toughness and 3) unique forging processes to manufacture the heavier, longer, integrated forgings for nuclear components as a pioneer and leader in the world. Based on these developments, JSW has supplied many large integrated forgings to worldwide and keeps the top share in the world. JSW's manufacturing experience of forgings for reactor pressure vessel (RPV) and steam generator (SG) since 1970 is shows in **Fig. 3**.

**Photos. 4 to 6** show typical integrated forgings for RPV.

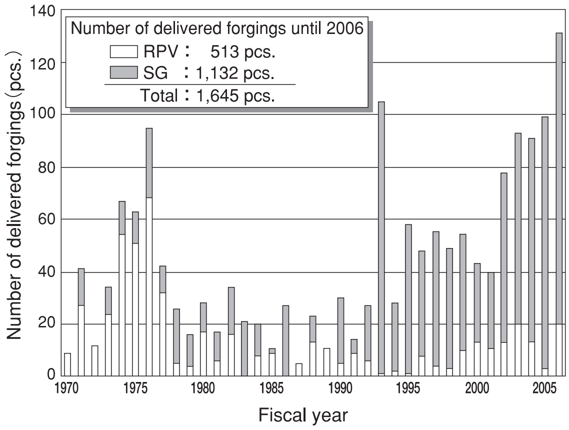


Fig. 3 Manufacturing Experience of Forgins for RPV & SG


Photo. 4 Bottom Petal for ABWR


Photo. 5 Nozzle Shell Flange for EPR


Photo. 6 Closure Head for PWRPV

(2) Development of Manufacturing Technology

①Making larger ingot

The former nuclear components had been fabricated by welding of formed plates. During construction and operation, it took much time for inspection of weld seams. In the beginning of 1970s, shell flange (for PWRPV) fabricated from 4 forged plate segments was manufactured as a first seamless ring form 400 tons ingot. Based on continuous technical development for making larger ingot, the world largest 600 tons ingot can be made at present. This largest ingot is being applied to manufacture of ABWR and EPR heavy forgings.[9], [10] ②Higher cleanliness and toughness

Material with low neutron irradiation embrittlement and higher toughness is required for RPV. In order to achieve these requirements, it is important to reduce the contents of impurity elements such as phosphorus, sulfur, copper and etc. This was achievable by application of double ladle refining/vacuum degassing technique[11] and selection of raw materials. Longer forged core region shell with 4.3 m height has been manufactured since 1980 so that weld seams would be located far from active core region.

③Unique forging technique

Outside pressing technique was developed in the beginning of 1970s for rings whose diameter were over the distance of press columns. Rings up to 8 m diameter can be manufactured by using this process.[11]

For SG forgings, several unique forging techniques were developed in 1980s, all parts of SG can be supplied as forging instead of casting and formed plates. JSW has been keeping very high share in replacement SG business since 1993.

④Manufacturing technology of stainless steel forging

Manufacturing technology of stainless steel forging were improved for prototype fast breeder reactor "Monju" based on developed technology for piping forgings of BWR.[12] At present, technology to get ultra low carbon content has been developed for large piping, shroud, grid plate forgings, etc.

(3) Future prospect

JSW's manufacturing capacity is one of key factors to design the material layout of components of nuclear power plant. JSW is keeping the position as pioneer of the integrated forgings by the continuous development of manufacturing technology. Recently, expectation is high for new nuclear power plants as clean energy contributing to improve safe supply of energy and to reduce the greenhouse gas emission. New constructions of nuclear power plants are started/planned in China, U.S., EU and other places as called Nuclear Renaissance. In response to increased demand of large forgings, JSW has decided investment plans to improve manufacturing capacity.

New construction programs have been announced. The third generation reactors AP-1000/ESBWR/APWR/EPR have been selected as passive safety designs in order to improve safety of plants. On the other hand, study of the forth generation reactor designs has been proceeded worldwide. It is considered to apply new materials, such as 316FR/9%Cr steel for fast breeder reactor, 9%Cr steel for high temperature gas reactor, and JJ1 steel developed in JSW for fusion reactor. JSW has started research and development programs of these new materials for next generation reactor designs.

*2.2 History of Steel Casting manufacturing*

Production of turbine Casings (TB shells) which are the important parts for energy industry field were started in 1955 and the quantity of TB shells increased according to the economical expansion. This quantity shows the max. number in 1970s including the big steel castings for ship parts, steel making facility's parts and construction facility's parts. **Fig. 4** shows our manufacturing Q'ty of TB shells and we notice the numbers are very big.

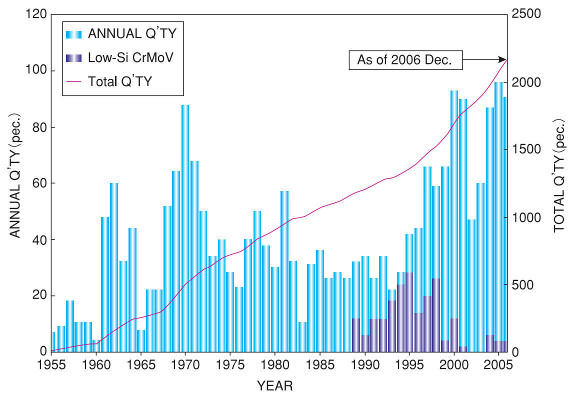



Fig. 4 Manufacturing Q'TY of Turbine casing

From the technical point of view, manufacturing technologies and facilities have been changed.

For example, 120ton electric arc furnace started to refine the molten metal instead of basic open hearth furnace from 1968 and molding method was changed from dry method to self curing method.

The computer simulation analysis is used for casting design according to the unidirectional solidification theory as the results of technical innovation.

Exporting casting ratio increased after 1975 and the designers of our customers said that they could see every type of TB shells in the world at JSW's foundry.

This indicated that the manufacturing technique level of JSW's foundry was very high in the world.

Then after we were trying to develop the technique to reduce casting defects for cost reduction caused by strong yen and by customer's requirement. Especially, the replacement of old facilities in the power station increased from 1990, and the new developed Low-Si-CrMoV material for TB shells was used in the case of replacement in order to elongate the life time and to reduce casting defects. We have applied many kinds of improved technology for manufacturing steel castings, for example, solidification analysis by CP., numerical evaluation of improvement actions, activity of improvement by small circle in our foundry workers, new molding sand system, wash, molding sand, tools for various operation, vacuum process during the refining etc.,.

The amount of casting defect became less than 1 by 20 compared with that of 1960 and this level of defect ratio is the lowest in the world.

These improved technologies were applied to the manufacturing of hydro turbine runners.

Hydraulic turbine runner changed to pump type runners according to power station sight condition of JAPAN. The height of water pool from the runner became very high because there is no place to construct hydro power plant with suitable condition. The stress of runner during usage becomes higher and higher according to the water pool height increasing and more severe ultrasonic test than that of forging parts is applied to important area of runner casting in order to satisfy the requirement of designer. We established the special technique for solidification control and quality control system to satisfy these requirements with the user (electric power company) and customer (fabrication maker) by co-operated research.

In recant year, The higher temperature steam is used in the turbine of fossil power station for getting the higher efficiency. The improvement of material was proceeded from 1980 for the Ultra Super Critical (USC) condition of power station where over 593℃ steam was used. And the improved 12Cr steel and new 12Cr steel were developed as the results of above material research.

The development was done with fabrication maker as co-operated research according to the each step for material design, laboratory test, manufacturing and evaluation of proto-type model and actual TB shell.[15),(16]

The first TB shell for KAWAGOE Power station of Chubu Denryoku K.K., which is the first USC Plant (31MPa, 566℃) in JAPAN and opened in 1989 was manufactured by JSW. (**Photo. 7**)[16]

We applied 3D-CAD and CAM system for casting design and pattern making in order to satisfy the customer's requirements which are cheaper price and shorter cycle time. And we developed the hybrid pattern by using above system and the pattern was made of wood, steel and plastic. This method made it possible to make pattern more short cycle time with more accurate reliability and repeatability even in the complex 3D surface which was difficult to make by old pattern making process, hand-made.

Photo.7 12Cr steel Turbine Casing for USC Plant (Weight : 39.7 ton)

We applied the one-sand closed system by using artificial molding sand to the manufacturing big steel casting as the pioneer of that system in the big steel foundry.

We could improve the amount of waste sand to 1/10 and the productivity to two times than that of old sand system.

The manufacturing cost of steel castings is still higher than that of new developed country, China, India etc.,. to our regret. But we will do our best toward the future for the supporting technical partner of designers in customer and user with our technology skill and reliability of our foundry.

## 3. Development of Manufacturing Technology for Large Capacity Hydroprocessing Reactor

### *3.1 Manufacturing of Hydroprocessing Reactor*

JSW began the manufacturing of reactors in 1962. At the beginning, the multi-layered shell type reactors were manufactured using thin steel plates. Thereafter, the heavy wall reactors, using (assembling) forged shell rings along with the improvement of the forging technology, became a main stream.

On the other hand, the operating condition of reactors had become more severe such as high-temperature and high-pressure hydrogen service, which required large capacity reactors with larger diameter and heavier wall thickness. Then, the demand of large capacity forged reactors increased and JSW has been following this trend. JSW is an eminent world wide factory having the large scale manufacturing equipments such as steel melting, forging, heat treatment, machining, plate rolling, welding and inspection, and the research laboratory. As always, JSW has been taking the lead in the development of the manufacturing technology of the hydroprocessing reactors in the world.

The solution activity of various problems related to the pressure vessel has been done through the close cooperation with Japanese and overseas oil refineries. Especially, the solution of the damage problem and the safety evaluation technology of the pressure vessels have been improved through the symposium between Japanese oil refineries, which was held periodically.

As of April 2007, more than 600 heavy wall forged reactors were supplied by JSW and they have been operated safely in 31 countries. JSW's manufacturing experience of reactors in licensor-wise is shown in **Fig. 5**.

*3.2 Improvement of Manufacturing Technology*

**Fig. 6** summarizes the historical improvement of the manufacturing technologies together with the change of size of hydroprocessing reactors regarding structural design, material manufacturing, welding, inspection and reliability analysis.

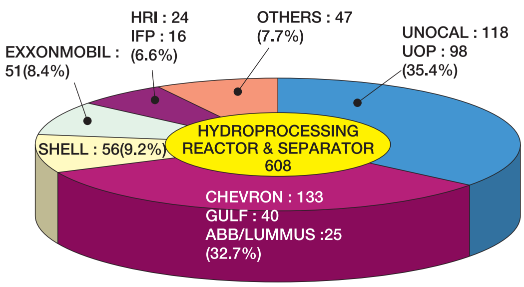



Fig. 5 Process Licensor-Wise Experience

*3.2.1 Material Manufacturing and Structural Design*

In 1962, the manufacturing technology of the conventional 2 1/4Cr-1Mo forged ring was established at JSW. Heavy wall forged reactors with the weight of 325m-tons, the inside diameter of 2,134mm, and the wall thickness of 211mm were manufactured for NIOC refinery/Iran in 1965. The length of a unit shell ring was approximately 2,500mm using 180m-tons and 220m-tons steel ingot at that time.

In the late 1960's, reactor inside diameter was enlarged to 3,000mm. In 1970's, a unit shell ring of 2,500mm in length for large size reactor with the inside diameter of 3,800mm and the wall thickness of 272mm was manufactured using the 250m-tons large-scale steel ingot. In the late 1980's, the manufacturing of a unit shell ring of length up to 3,500mm became practical by the improvement of the steel ingot shape, the discard volume of the steel ingot end, the forging methods, and the material yield rate. The longer forged shell ring contributed to the decrease of the number of girth weld joints for reactors. Moreover, the manufacturing of one-piece head without segmental weld seam became practical by hot-forming of the heavy thick plate which was made by the wide plate rolling mill from large-scale steel ingot. In 1993, the heaviest reactor of 1,453m-tons in the world with the inside diameter of 4,500mm and the thickness of 273mm was delivered to the Netherlands. In 2002, the reactors with the largest inside diameter of 5,200mm, the thickness of 277mm and the weight of 1,000m-tons were manufactured for overseas. In 2006, the

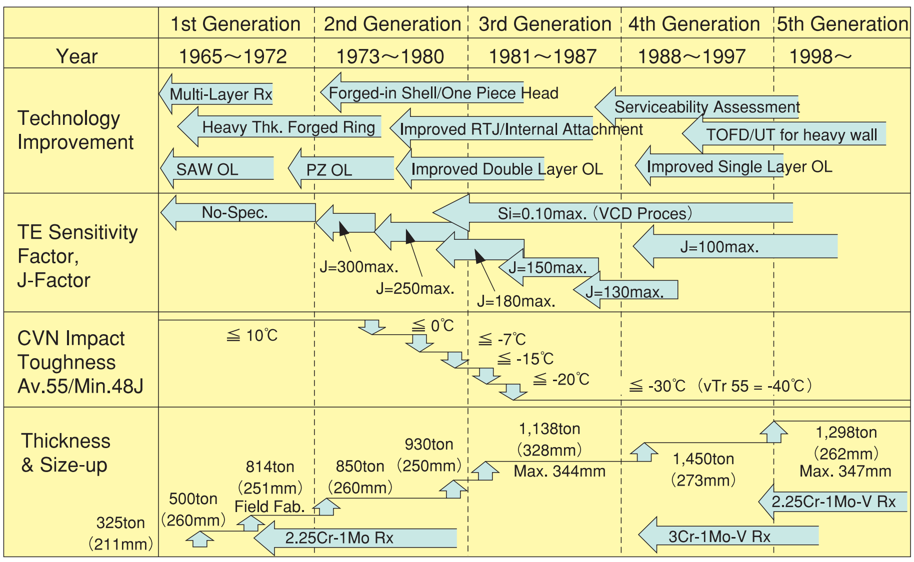



Fig. 6 Historical Improvement of Main Manufacturing Technologies

reactors with the heaviest wall thickness of 347mm, the inside diameter of 5,200mm and the weight of 700m-tons were manufactured for overseas.

**Photo. 8** shows the 1,200m-tons reactor shipped to South Korea in June 2007. **Fig. 7** shows the topics of manufacturing experience of large size hydroprocessing reactors up to now.


Photo. 8 Land Carriage of 1,200m-tons Reactor by Trailer

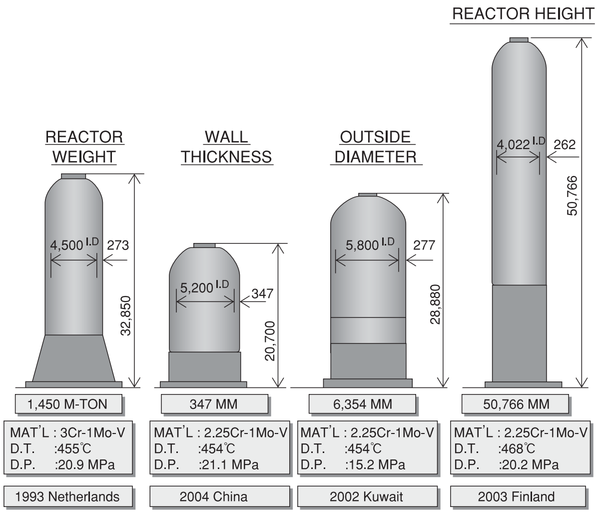



Fig. 7 Topics of Manufacturing Experience of Large Size Hydroprocessing Reactor

In the area of the structural design, there was a cracking problem of skirt attachment weldment of reactor previously. The reason of cracking is the high stress concentration occurred by the thermal gradient between skirt attachment area and skirt base plate, and the large static load by the reactor self-weight including the catalyst and the crude oil occurred in the skirt attachment. In order to avoid such problem, JSW established the manufacturing method of "Forged-in Shell Forging" with our own original technology. This structure, which avoids the welded portion from the stress concentration area, is being used as the world standard now.

Moreover, many cracks by the $\sigma$-phase embrittlement and hydrogen embrittlement in the austenitic stainless steel weld overlay of bottom corner of nozzle gasket groove (ring joint type) occurred frequently in reactors manufactured in 1960's. As the countermeasure of the problem, JSW improved the final layer's ductility by changing the welding sequence and reduced the stress concentration utilizing larger corner radius. These preventive countermeasures of crack initiation in the gasket groove have been adopted as the world standard. (17)

In 1972, JSW suggested the J-factor control to reduce the susceptibility of temper embrittlement which is the aging degradation phenomenon occurred in 2 1/4Cr-1Mo material reactors operated at high temperature. The J-factor control based on the control of quantity of Si, Mn, P and Sn is specified in the basic material specification by process licensors and end users all over the world. (18)

Conventional 2 1/4Cr-1Mo steel has been used for hydroprocessing reactors until the late 1980's from the late 1960's. Then, 3Cr-1Mo-V steel which has higher tensile strength at 454℃ and higher creep strength was developed by JSW. The higher design intensity value can be obtained by using this material. The first commercial reactor using 3Cr-1Mo-V steel was manufactured by JSW in 1989. (19) Now, 39 reactors made of 3Cr-1Mo-V steel are being operated safely. In 1999, the reactor made of 2 1/4Cr-1Mo-V steel was manufactured. 2 1/4Cr-1Mo-V steel is adopted as the main steel material for hydroprocessing reactors now. This material including welding material provides stable quality as the reactor material for heavier wall thickness and larger diameter, although Vanadium is added.

### *3.2.2 Welding Technology*

In the head, the shell, and the nozzle weld joints of reactors manufactured till 1970's, general welding sequence was that the first step was front side welding, second step was back chipping of 2-3 passes, and third step was the back side welding. After 1983, the welding bevel of one side weld type was adopted which avoided back side welding. The welding method without back side welding greatly improved the efficiency of welding work. The same method is adopted in the girth weld of the shell and the head at present. In addition, the recent design of welding bevel is U shape narrow gap with the outside width of 27mm regardless of any welding thickness, and two pass welding in one layer is applied in full thickness now. Their contribution to the shortening of welding time and the increment of annual production for the heavy wall reactor is remarkable. The welding process in the weld joint of the heavy wall reactor is a Submerged-Arc Welding (SAW) method. The application rate of machine and automatic welding in all welds is improved up to 97%. The tandem SAW method is applied to the girth weld, which provides stable quality of the weld. Stainless steel weld overlay cladding process with the wide strip electrode has been applied since 1972. The disbonding of weld overlay in the interface between the first layer and the base metal was detected by UT after a long term operation in reactors manufactured till early 1970's. The resistance to the disbonding of weld overlay was greatly improved by the improvement of welding condition and the chemical composition of the welding material in 1978.[20]

From the beginning of 1990's up to the present, hydroprocessing reactors have been manufactured from 3Cr-1Mo-V and 2.25Cr-1Mo-V steel with excellent high temperature tensile strength, creep strength, and resistance to hydrogen embrittlement. The research laboratory engineers and the welding engineers are studying and improving the method of heat control to avoid the re-heat crack and the cold crack of these material aggressively, that contributes to the establishment of the welding technology of V-addition steel. Moreover, the weld overlay of single layer method in lieu of double layer method becomes to be adopted due to the better resistance to weld overlay disbonding of V-addition steel, that has improved efficiency of the overlay weld.

*3.2.3 Inspection Technology*

In 1960's, radiographic examination (RT), magnetic particle examination (MT) and liquid penetrant examination (PT) were applied as the inspection methods for surface and internal quality of weld. The ultrasonic examination (manual UT) was introduced into ASME (American Society of Mechanical Engineers) Boiler & Pressure Vessel Code in 1964 after the destruction accident of pressure vessels. In 1993, the Mechanized UT method of automatic scanning and record type (represented by TOFD) was developed at first in Europe, and JSW applied TOFD to the reactor for the Netherlands for the first time. The TOFD equipment was introduced into JSW in 1995 though it was registered as Code Case 2235 in ASME Code in 1996. In 1998, JSW applied the Mechanized UT inspection to the reactor for the U.S.A., which was JSW's first experience for ASME Code vessel. At present, Mechanized UT method to inspect the internal quality in the weldment is becoming general inspection method. As a result, the transportation frequency of a large-scale reactor (800-1200m-tons) to the radiographic examination room was reduced, and this inspection method contributes largely to the shortening of the production schedule of reactors.[21]

On the other hand, JSW is performing the maintenance inspection (Mechanized UT, manual UT, MT and PT) for reactors in Japanese and overseas refineries aggressively after long term operation and has established a consistent maintenance system from the maintenance inspection to the diagnosis and the countermeasure based on the maintenance inspection results. At present, JSW is utilizing its own developed diagnosis system software to evaluate the soundness of reactors in Japanese and overseas refineries based on the accumulated data (hydrogen embrittlement, temper embrittlement, the characteristics of crack propagation rate and etc.).[22]

*3.3 Future Technology*

The energy demand is increasing rapidly in worldwide. The main energy sources are coal, oil, natural gas and nuclear power, of which each necessary quantity is increasing. In most oil refineries, heavy crude oil is refined to light oil, of which the trend is activated under the situation of increasing oil prices. That movement requires the market increment of large scale heavy wall reactors, which is expected to continue several years. However, it is necessary to continue the improvement and development of the manufacturing technology of reactors studying the market trend and refining process technology in the future.

It should be noted that reactor wall thickness calculations using the rewrite version of ASME Sect. VIII, Div.2 (issued in July 2007) results in wall thickness of reactors 16 percent less than that calculated based on the old version. It is important to watch and study the market trend of the requirements for reactors.

Considering the above situation, JSW is going to make progress in the improvement and the development of the following manufacturing technology of reactors as the manufacturer who can make material for reactors, fabricate reactors and inspect reactors.

1) Technological development based on market research through information of process licensers and end users
2) Design engineering based on Div.2 rewrite version

3) Total evaluation technology of aging reactors

## 4. Development of natural gas as an alternative energy source and expansion in demand for clad steel pipe.

### *4.1 Increasing energy demand and outlook for natural gas*

Due to the increase in energy demand created by the economic growth of Asian countries, including China and Japan, many are predicting a large increase in demand for fossil fuels such as oil, coal and natural gas. Even among these, natural gas is predicted to have the greatest growth due to its advantages as an energy source.

In other words, natural gas has good combustion characteristics of comparatively less carbon dioxide and nitrous oxides exhaust than oil. Further, compared to oil, which is concentrated in the Middle East region, natural gas is considered to be a more reliable energy source as it is distributed over more varied region of the world, and there are abundant reserves.

### *4.2 Natural gas production and expectations for clad steel pipe*

The major component of natural gas extracted from gas fields is methane, however it is an extremely corrosive gas (sour gas) that contains impurities such as water, hydrogen sulfide, chlorides and carbon dioxide. This is first sent to processing facilities where the water is removed.

This is to say, a higher corrosion resistance is required of the pipeline material used to transport the sour gas from the well to the processing facilities, and in sections of the processing facilities. JSW clad steel pipe was evaluated as one of most possible solution for such applications, and we supplied lot of clad steel pipe to all over the world. Digging up the natural gas started from the onshore and moved to the shallow offshore.

However with increased demand there will be a shift from shallow offshore to deeper offshore with more corrosive environments.

In shallow offshore gas fields, the demand for clad steel pipe was limited since the extracted gas is transported to the nearest process platform where the water are removed.

When the well is located in deep water (depth > 150 m), it has become common to apply a method in which the gas is transported without processing from the well to a remote land-based gas preprocessing facility (sub-sea manifold method) as this is more economic than the platform method. Thus there has been a huge increase in demand for highly corrosion resistant and economic clad steel pipe. (**Fig. 8**)

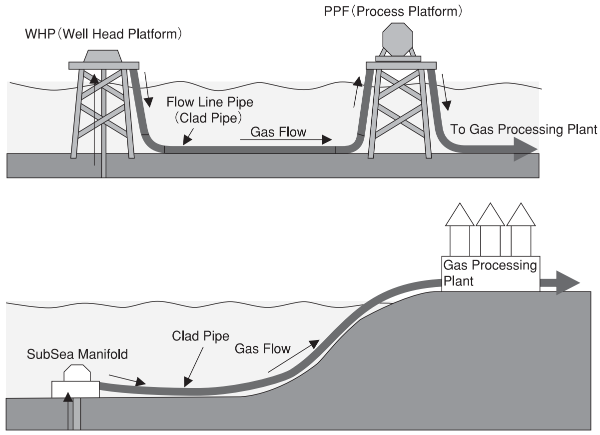



Fig. 8 Comparison of platform method and sub-sea manifold method.

JSW have been able to handle the demand increase by both technical improvements and increasing production capacity.

### *4.3 The development of clad steel plate*

JSW started development and production of clad steel plate produced by hot rolling in the 1950s, and with simultaneous application development, we have contributed to many industrial fields. Clad steel pipe for natural gas transport is also positioned as an important field of application.

In order to handle the increase in demand for clad steel pipe, we have also increased our production capacity, and expanded by increasing facilities such as a large roller leveler and heat treatment furnace.

### *4.4 Development and production of clad steel pipe*

A clad pipe was developed for the expansion of the clad steel plate usage in the 1970s when JSW started fabrication of longitudinal welded clad steel pipe for sour gas transportation, and the first clad steel pipe was delivered to NAM / Holland in 1978. We have continued to deliver into this field up to the present.

In 1993, clad steel pipe was standardized by the American Petroleum Institute (API), and JSW was the first company to receive their certification.

Clad steel pipe uses clad steel plate manufactured by hot roll bonded process as the raw material, while the forming method is the press bending, easily managed to adjust variable plate thickness

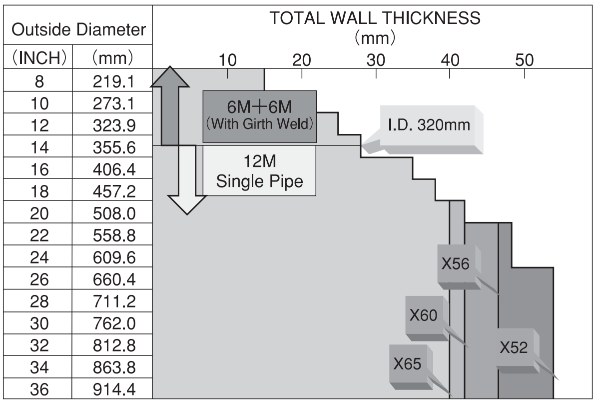


Fig. 9 manufacturing scope of clad steel pipe

and diameter.

In **Fig. 9** the manufacturing scope of clad steel pipe is shown for each plate thickness and diameter. The smallest diameter is 8", and while the largest diameter will depend on pipe length, we manufacture up to 36" as standard.

It's possible to utilize a large range of cladding materials, from austenitic stainless steel to highly corrosion resistant Ni-based alloys.

In 2004, JSW made a significant capital investment in its pipe manufacturing line, centered on a 13 m forming press (**Photo. 9**), then a further capital investment in 2006 based around welding facilities and inspection equipment, thus advancing its capital infrastructure to handle the increasing demand for clad steel pipe and achieving a 30% increase in production capacity within this period.


Photo. 9 13m forming press

*4.5 Performance of clad steel pipe*

Clad steel pipe for pipelines requires a high reliability because of its environment.

E.g. pipeline standards concerning toughness are strictly stringent. JSW has promoted development as there is a demand for not just low temperature toughness of the backing material, but the energy of absorption vE-40 degree Celsius in a Charpy impact test even on welding HAZ sections must be more than 35J.

**Fig. 10** shows the impact characteristics at the

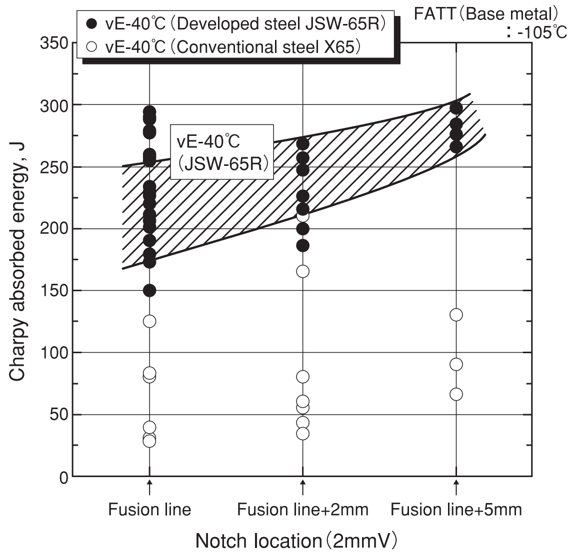


Fig. 10 Impact characteristics at weld of JSW-65R clad steel pipe

HAZ in a GMAW-MC weld. The charpy energy vE-40 degree Celsius shows a higher absorbed energy more than 100J at the HAZ.

In order to correspond the recent trend for higher strengths material such as conventional X65 backing material, JSW is also promoting the development of clad steel pipe using X70 grade as the backing material.

*4.6 Future prospects*

From the large range of applications up to the present, clad steel pipe is positioned to be an indispensable material for natural gas drilling and production.

As stated above, in order to handle the great increase in demand for clad steel pipe brought on by the increasing demand for natural gas and changes in drilling methods, in recent years JSW has successively made large capital investments and established production processes.

JSW is the only one clad steel pipe supplier who manufacture clad steel plate and clad steel pipe, we intend to maintain our delivery structure, to continue to make quality improvements and new material development, to discharge our delivery responsibilities and to support the energy industry now and into the future.

## 5. Approach on Wind Power Generation Business corresponding to Expansionary Policy of Renewable Energy Use

*5.1 Current State of Wind Power Generation*

A recent energy issue is roughly classified into stable supply of energy and global environmental issues, for example, global warming. Though the introduction of new energy has been originally promoted to the purpose of the spread of non-petroleum energy source, new energy is now noticed as environmental friendly energy because it contributes to the correspondence of global environmental issues.

Wind power generation, which is comparatively excellent in the economy of power generating cost, the efficiency of utilized capacity and environment of carbon-dioxide emission in new energy, has been rapidly introduced around Europe and America as the leading part of renewable energy from the latter half of the 1990's along with enlarging of generator capacity. Total installed capacity of wind power generation in the world at the end of 2006 is about 74,300MW.

A continuous increase of wind power generation in Europe and America, and rapid increase in China and India are expected, worldwide expansion of wind power generation is progressing.

The introduction of new energy in Japan has been promoted by the energy policy based on RPS (Renewable Portfolio Standard) rule enforced in 1997. The amount of total wind power generation was reached 1,400MW at the end of 2006, it is expected to increase to 3,000MW in 2010.[(24), (25)]

*5.2 Technological Issues of Wind Power Generation*

A current technological issues of wind power generation in Japan are divided into the following three items.

1) The wind power generation cost is still high compared with existing thermal power generation etc., though it is comparatively low-cost in new energy. The wind turbines, which can reduce the power generating cost by decreasing of the cost of construction and improving of the utilized capacity and operating rates, is demanded.
2) There is a feature in Asian region including Japan that the mean wind speed is low and the extreme speed of the wind by the typhoon etc. is high. Moreover, the thunder with big energy shows the tendency to happen frequently on the Sea of Japan side in winter. The construction of the Japanese type wind power generation system that can correspond to peculiar meteorological conditions of Japan is needed.
3) There is a possibility that the electric power quality decreases by the voltage change and the frequency variation when wind power generation is introduced on a large scale. Moreover, the transmission grid in Japan is generally weak in the region that is appropriate for the wind power generation. The development of the wind turbines with a little influence on the grid is desired.

*5.3 JSW's Approach and Aim for Wind Power Generation*

JSW started to manufacture the tower of the wind turbines in 2000. Afterwards, the tower for a large-scale wind turbines has been continuously manufactured. Moreover, sales of the wind turbines made of a European manufacturer and the construction work of the wind turbines also have been carried out. Manufacturing of the blades was started at Muroran Plant in October, 2005. JSW introduced the basic technique of the multipole permanent magnet synchronous wind turbines from Europe, develops the detailed technique, and attempts the business expansion aiming to become the comprehensive manufacturer of the wind turbines.

1) Tower

The tower for 1500KW wind turbines is steel plate welding construction of division into three pieces with 65m in height of the hub, maximum diameter of 4100mm, and weight of 90tons. The manufacturing experiences of the tower are about 130pcs. The tower is safely designed for the extreme speed of the wind at the typhoon and the earthquake of the peculiarity to Japan. JSW1s experienced processing technology of the tower is evaluated to be high quality.

2) Blade

The production of the blades was started based on licensing-in from the Netherlands in October, 2005. The manufacturing experiences of 34m length blades are about 60pcs. The blades are safety designed and manufactured to endure 70 m/s speed of the wind, materials of the blades are the glass fiber and epoxy resin. A mass receptor is installed in the blade tip, and it prevents from damaging the blades by the thunder.[(26)] Because the blades are manufactured with RIM method (resin injection molding method) using the molds, a steady product quality can be secured. The molds for 40m length blades were manufactured last year. Continuous production of 40m blades that are a standard blades of the wind turbines for 2000KW has already started.

3) Wind turbines

JSW starts to sale 2000KW wind turbines equipped with the multipole permanent magnet synchronous generators(27) in 2007. 2000KW first wind turbine installed in the Muroran Plant last year is shown in **Photo. 10**. This wind turbine has the feature that the inrush current having a bad influence on the grid is hardly generated because the multipole permanent magnet synchronous generator is installed. This wind turbine also has the advantage with a little influence on the grid because variable speed operation system according to the wind speed is adopted. In addition, because the gearless mechanism is adopted in this wind turbine, it contributes to decrease the stop time of the wind turbines by gear troubles. This wind turbine is expected to suit to natural environment in Japan and Asian region. JSW also urges research and development concerning the accuracy improvement for prediction and analysis technics of wind condition(28). **Fig. 11** shows the analysis example of wind condition. JSW wants to contribute to further development of domestic wind power generation while attempting the improvement of its own wind power generation technology hereafter.


Photo. 10 2000kW Wind Trubine

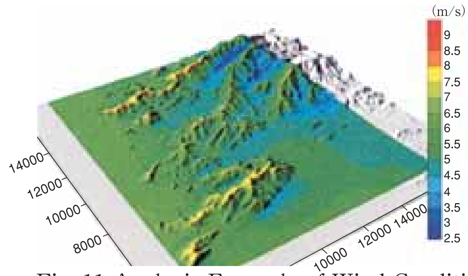


Fig. 11 Analysis Example of Wind Condition (Mean Wind Speed at Hub Height 89m)

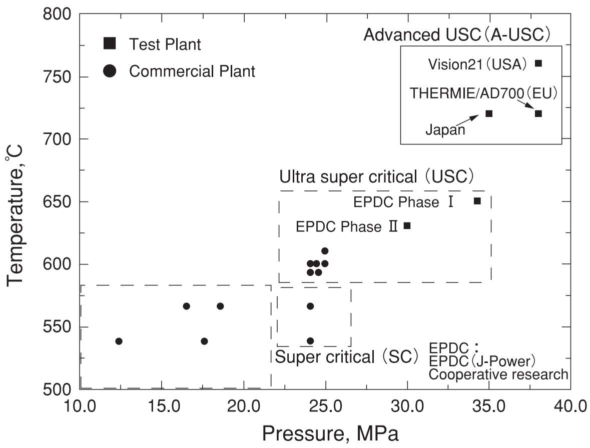


Fig. 12 Change in steam temperature and pressure

## 6. Future prospects of the material research focusing on the trend of energy industry

### *6.1 Prospect of the turbine rotor shaft forging materials for elevated steam temperature*

Increase in the steam temperature of fossil power plants has been progressing aiming at the improvement of efficiency of the plant. The increase of efficiency significantly contributes to the reduction of $CO_2$ emission. **Fig. 12** shows the change in steam temperature and steam pressure of coal fired power plants in Japan together with the steam condition of several test project. In Japan, the EPDC (J-Power) cooperative project for the development of ultra super critical (USC) power plant with the steam temperature of 650℃ has been performed with successful results and, at present, commercial plant of the steam temperature of 620℃ is under construction.(29) On the other hand, development of the plants with steam temperature over 700℃, advanced-USC (A-USC), is also progressing. The project was first started in Europe and a national project is going to be commenced in Japan(30). In order to follow these trend, JSW has performed the development of materials and production technologies, such as high pressure (HP) turbines and intermediate pressure (IP) turbines made of advanced 12CrMoV and/or new 12CrMoV steels for USC power plnats. The efficiency of power plant is around 42% for steam temperature of 600℃ and efficiency can be raised approximately 46% in the 700℃ A-USC power plant. For high temperature components in the A-USC power plants, however, Ni-base super alloys which passess sufficient creep strength need to be used. Since there is no experience in the production of large steam turbine forgings made of super alloy in the world, the establishment of production technologies of segregation free large super alloy ingot and forging technology of large Ni-base alloy must be the key for realizing the components of A-USC plants. At present, the materials have been developed through the cooperative research with turbine builders. Formation of the segregation and possibile ingot size are investigated by using originally developed simulation technologies and experimental method. On the other hand, weld-construction type turbine rotor made from super alloy and 12CrMoV steel, is also designed instead of the monoblock super alloy forging. In such design, further increase of creep strength of 12CrMoV steel is desired. In order to attain the higher creep strength, premature-fracture problem disclosed in the development of new 12CrMoV steels should be avoided and investigation has been continued to solve the problem and to realize the higher creep strength 12CrMoV steels.

AUSC, IGCC, IGFC and LNG power plants will be constructed as the new power plants or replacement of ageing power plant and JSW will continue the research and development of the materials and production technologies of components for these plants and will supply the high performance components to the world.

*6.2 Development of components for new generation nuclear reactor pressure vessels*

Since the nuclear power generation has come to a predominant opinion as the $CO_2$ emission free power generation system, the number of construction of new and replacement nuclear power plants will surely increase in the future.

At present, most of the nuclear power plants are the light water reactor (LWR) plants, that is to say boiling water reactor (BWR) and pressurized water reactor (PWR) plants. The BWR and PWR are further improved to be advanced types of BWR and PWR such as ABWR, APWR and Euopean type PWR (EPR) on the standpoint of economy, safety and so on. JSW has already supplied a large number of forging components for conventional and advanced type reactors. In addition, the energy strategy of Japan adopted plans of several new nuclear reactors, such as fastbreeder reactor (FBR), high temperature gas cooled reactor (HTGR) and fusion reactor (FR). In the project on development of FBR, completion of demonstration plant is scheduled to be 2025 and commercial plant will be in service in 2050. The reactor vessel of FBR will be made of type 316FR stainless steel, and 9%CrMoV steel is adopted as the material for steam generator components. Since the diameter of the vessel is much larger than that of "Monju", which is made of 304 stainless steel components supplied by JSW, advanced production technologies will be required in the production process such as steelmaking, casting, forging, heat treatment, machining and so on. In the case of 9%CrMoV steels for steam generator, there are several points to be clarified. Concerning the producibility of large ingot and heat treatment, investigation has already started. Several types of HTGRs, such as PBMR, VHTR and GT-MHR have been designed(31). Commercial plant of PBMR in Republic of South Africa is under construction. As the materials for these reactor pressure vessels, ASME SA508 Gr.3 Cl.1 and/or SA336 Gr.91 (9%Cr steel) are adopted. In case of fusion reactor, the construction of "ITER" will start soon and the JJ1 steel developed by JSW will be applied for the material of a part of TF coil case which is used at 4K.

In addition, development of several types of the nuclear reactors called generation IV are progressing aiming at the realization in 2030. For these new plants, request for the high performance and high reliability material and components will increase significantly.

*6.3 Nanotechnology and material*

It has been long time since the word "nanotechnology" was used. In the metallurgy, researches to attain the advanced and/or new properties through the control of microstructures in the scale of nanometer. For example, high strength and toughness can be obtained in the ultra fine grained steel (material) which develops the sub-micron size grain microstructure(32). The dispersion of precipitate in the order of nanometer and ultra high purity material are also in the concept of nanotechnology. It seems to be difficult to adopt these nanotechnology in the process technology of large forgings. However, National Institute for Mterials Science (NIMS) succeeded in manufacturing 35mm thick ultra fine grain steel forged plates by using 300 ton press in JSW and confirmed its high strength and toughness. Research on the ultra fine grained steel has been continuing seeking the advanced properties. The investigation of ultra high purity steel is also continuing. Refining by using hydrogen gas and production of high purity material by a cold crucible (CC) furnace are progressing. High nitrogen steels produced by pressurized melting or a pressurized ESR furnace have also been studied.

By applying these advanced or new production technologies and equipment in the steelmaking, casting and forging process, JSW will realize further high quality and high performance materials.

*6.4 Development of Hydrogen Absorbing Alloys and Applied Hydrogen Storage Tanks toward Forthcoming Hydrogen Economy*

Although fuel cells and hydrogen economy are expected in the future to solve the many environmental and energy problems, the technologies of hydrogen storage become large subject on hydrogen utilization(33). Compressed hydrogen gas and liquefied hydrogen are well known as hydrogen storage methods, and hydrogen storage materials are highly expected for efficient hydrogen storage. **Fig. 13** shows the relationship between gravimetric and volumetric storage density of some hydrogen storage materials, states of hydrogen and typical storage systems. The distance between hydrogen atoms of metal hydride is smaller than that of liquefied hydrogen, so metal hydride can store a large quantity of hydrogen in a small space. The hydrogen absorbing alloy, a kind of metal hydride, can absorb and desorb hydrogen reversibly around room temperature and can store hydrogen at relatively lower pressure. JSW had started the development of TiCrV alloy and continues the research to improve the hydrogen capacity and to apply the alloy to practical use. Inorganic materials like NaAlH4 and organic materials named organic hydride are also expected because of their high gravimetric hydrogen density, but their volumetric density restrains to low level due to their small specific gravity. Furthermore, they need high temperature over 150℃ for hydrogen release. The caloric equivalent hydrogen density of gasoline and methanol are also shown in Fig. 13. The energy density equal to gasoline is required applying hydrogen storage material to vehicle.

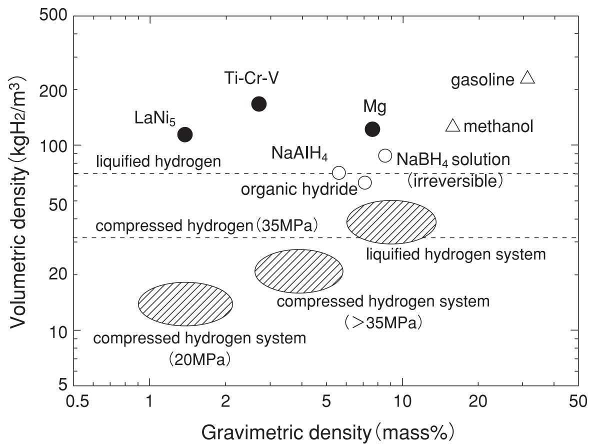



Fig. 13 Comparison with hydrogen storage density

JSW has developed the hydrogen storage tank containing the metal hydride (hereafter, MH tank). Automobile companies activated development of the fuel cell vehicle since around 2000. Accordingly JSW has provided many on-board MH tanks to them and delivered a large hydrogen storage and supply system of 75 Nm$^3$ in hydrogen storage capacity to the first hydrogen station built in Takamatsu city. Further, the MH tank of 100 Nm$^3$ used for the underwater vehicle in 3 years has been developed and delivered in 2004 to Japan Agency for Marine-Earth Science and Technology that developed the autonomous underwater vehicle "URASHIMA" powered by a fuel cell. **Photo. 11** shows the MH tank mounted in the URASHIMA. In 2005, the URASHIMA achieved 317km continuous cruising and established the world record in a sea trial in Suruga Bay. On the other side, it is foreseen that the practical use of the fuel cell will be proceeded in fields of portable electronics and small vehicles, and the market will become alive around 2009. The practical use of the MH tank is expected in such application fields which make much of compactness than weight. JSW has developed a small and high performance MH tank by applying the high density packing technology of metal hydride and provide it to domestic and foreign companies developing the micro fuel cell for the mobile phone and the independent power supply. JSW also developed the manufacturing process for mass production. In addition, the market of a fuel cell scooter in Taiwan is expected to begin soon, and we have a plan to supply metal hydride to the business.

The protonexchange membrane fuel cell is widely noticed as a key device of the hydrogen energy society, and the development of a fuel cell vehicle, a residential fuel cell, and a portable fuel cell have been proceeding. As for the hydrogen storage


Photo. 11 Fuel cell underwater vehicle "URASHIMA" and MH tank

and supply, although the compressed hydrogen gas is major method for hydrogen storage and supply, development of a higher efficiency hydrogen storage material is desired. Various storage systems are under development such as high pressure MH tank system for automotives and methanol, hydrogen absorbing alloy, and chemical hydride system for portable use. JSW aims at the application of MH tank for portable fuel cells and independent small power supply through the development of small and high efficiency MH tank based on the filling technology of alloy to a high density. Moreover, JSW is capable of providing large MH tank to practical use by controlling the hydrogen absorbing and desorbing rate of hydrogen absorbing alloy for the application of MH tank, such as underwater vehicle URASHIMA.

## 7. Conclusions

The changes in technology at Muroran Plant mainly in the last 50 years of a hundred years of history of JSW are summed up and current activity including future outlook is also introduced.

There are a number of approaches to promote technology-based business such as development of new products or new market by combination of technical innovation and accumulated proprietary technology, strategic approach taking technology import or alliance based on market trend analysis into account, making existing products competitive and expanding business by technology upgrading and improvement of manufacturing process and productivity, creation of new demand by distinctive elemental technology or highly-functional materials.

At the same time, it is necessary to supply technologies at right timing in accordance with world's demand or progress and maturity of social infrastructure and to see widely how to bring JSW's technology to the market including other industries', as materials, system components or production equipment in various phases or stages.

In adopting technology and products focusing on energy and preservation of environment, which is JSW's slogan as the main subject of this paper, it is possible to look over various phases or stages to get the chance to show effectiveness of JSW's technology by strengthening the base of progressive and sustainable action looking from material development to commercial products realization.

Therfore JSW Muroran Plant will step forward to the evolution to globally-esteemed manufacturing plant, paying great attention to materials and its manufacturing process development and also concentrating in development of human resources and in passing down its technologies.

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