History of Technical Developments in JSW for a Century

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—Synopsis—

The Japan Steel Works (JSW), Ltd. was founded as a manufacturer of high quality steels for domestic production of weapons and developed materials technologies such as steel making, casting, forging, rolling and chemical analysis for manufacturing heavy-section castings, forgings and steel plates and machinery technologies for fabricating artillery and tanks. After World War II, JSW adapted itself to fulfill industrial needs, utilizing its proprietary technologies and the introduction of overseas technologies, and has become an integrated manufacturer of materials and machinery to produce the components for turbine and nuclear power generation, large reactors for oil refineries, clad steel plates/pipes, plastic processing machinery such as pelletizers, extruders, film forming machines, blow- and injection molding machines and various industrial machines. JSW has intensively supported not only the economic growth in Japan but also energy developments throughout the world, and is about to step forward to its second century, adding the production equipment for information technology industry to its lineup. A hundred years of technical developments in JSW are outlined.

1. History for the Last 100 Years

1.1 From Foundation to the End of World War II

The Japan Steel Works, Ltd. (JSW) was founded in 1907 as a manufacturer of high quality steels and weapons partly according to the orientation of the Imperial Japanese government. Upon the foundation it built Muroran Plant and installed a 50 ton open hearth furnace, a 4,000 ton hydraulic forging press and a variety of precision machining equipment, to start manufacturing weapons.

The production increased through the extended armament of the imperial army and navy during World War I, and the production facility was expanded accordingly. Meanwhile, technologies such as degassing upon making large ingots and phosphorous elimination by a basic open hearth furnace were developed. The basis of manufacturing large forgings and castings in later days was thus established. As a less known fact, JSW produced 100 HP aircraft engines in 1918 for the first time in Japan (**Photo. 1**).

Photo. 1 First Japan-made aircraft engines.

Following Muroran Plant, Hiroshima Plant (1920), Yokohama Plant (1936) and Musashi (Fuchu, Tokyo) Plant (1941) were built as machinery plants in response to the armament expansion plan of the government. Thus JSW became an integrated manufacturer of steel and machinery products for mainly military uses such as heavy gage cannons, thick and wide armor plates, small- and medium gage artilleries and tanks.

While heavy gage cannons including the 40cm cannons installed on the battleship "Mutsu" (**Photo. 2**) are well-known as the main products before World War II, industrial products such as refrigerators and freezers for naval vessels, forgings for railways, high pressure hydrogenation reactors for ammonia fertilizers were also put into the market, which would become the main products after the war. As a result of research work at the research laboratory in Muroran, which had started at the same time as the plant operation, a quantification method of hydrogen in steels was invented for the first time in the world. This

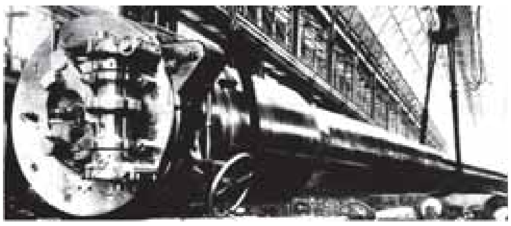


Photo. 2 A 40cm cannon under fabrication at Muroran Plant.

Representative Director, Vice President and Director of R&D Headquarters

achievement was promoted by the investigation of white spots that were frequently observed in large-scale forgings in the 1930's and became the origin of a series of study on hydrogen-caused defects of steels and studies on hydrogen energy, which have been carried out to date. As for the facility, the 10,000 ton hydraulic press imported in 1940 from Germany was the largest hot forging press in the world and is still main equipment for manufacturing steel products in JSW through the recent remodeling to a 14,000 ton press, together with the 4-high hot rolling plate mill also imported from Germany at the same time.

1.2 Developments after the War and Expansion of Technologies

1.2.1 Steel Products and Their Technologies

After the war, JSW oriented itself to apply the inherited casting and forging technologies to industrial products. In the recovering movement of industries from damages of the war, castings such as runners for hydraulic power generation and forgings such as rotor shafts for steam turbines and crank shafts for marine engines were manufactured. For the steel industry, production of cast rolls, forged rolls and roll housings was started. Thus the lineup of cast and forged components was gradually built up for the power, marine and steel industries. These products all followed a tendency toward larger sizes as Japanese economy grew at a very high rate and industries demanded large-scale facilities.

As for steel plates, stainless steel clad plates, which were made through hot roll bonding of a stainless steel plate and a carbon steel plate, were developed in addition to thick plates for boilers and ship building. Weldable high strength steel plates with tensile strength over 590 MPa were developed as pioneer work in Japan using a direct quenching method and were delivered to be applied to pressure vessels, bridges, pipes and ships. Furthermore, upon the construction of first nuclear reactor in Japan, JSW successfully delivered high quality pressure vessel steel plates in a short period for replacing imported plates, in which hydrogen caused defects had been found. This opened a way for JSW to become a supplier of nuclear reactor components. The fact that a set of boiling water nuclear reactors (BWR) were fabricated and deliver-ed to Taiwan Electric Power in 1972 made JSW establish a complete manufacturing system for nuclear reactors including the quality assurance, which became a basis of supplying heavy gage forged components almost exclusively in later days.

Fabrication of large-scale petroleum refining pressure vessels was started at JSW in 1964, when a high pressure reactor was delivered to Kuwait after experiences with high pressure reactors for synthesizing fertilizers and with multi-layered pressure vessels. Capability of manufacturing heavy gage hydrogenation reactors with forged shell rings won tremendous reliance from worldwide petroleum producers and resulted in a high share because these reactors did not have weld lines along the longitudinal direction, in which the highest stress would be exerted on the operation under high pressure.

Since equipment in the energy industry was increased in size for improved energy efficiency during the economic growth, forged products especially rotor shafts for power generation, nuclear reactor components and petroleum refining reactors became larger and heavier. Movements for improved reliability of these equipment and components were promoted at the same time typically by organizations of international standards. In response to these requirements, manufacturing technologies such as steel making, forging, heat treatments and machining were continuously developed. As a result, a consecutive production system of heavy gage forgings with high quality has been established at JSW Muroran Plant, which could not be observed anywhere else in the world.

With respect to steel making, introduction of various facilities and technical developments were carried out in order to lower gaseous elements like H and O and impurity elements such as P and S that cause damages in steels and to suppress macro segregation for homogenization of large ingots. After combined refining by means of acidic and basic open hearth furnaces was employed for a while, pouring in vacuum was begun in 1960, when Bochumer-Verein type mold stream degassing equipment was introduced. Introduction of a steam ejector further improved the degree of vacuum, and the process of melting and refining became to be completely conducted with electric arc furnaces. Associated with introduction of vacuum casting, vacuum carbon deoxidization (VCD) was successfully developed, which led to improved characteristics of large ingots such as finer dendritic macrostructures, suppressed macro segregation and lower susceptibility to temper embrittlement due to elimination of Si as deoxidizer. Together with increased ingot sizes, multiple pouring of plural heats in ladle furnaces with separately adjusted chemical compositions was developed (**Fig. 1**), which made the producible ingot size gradually increase. In the 1980's lowering gaseous and impurity elements exhibited further progress because installation of vacuum equipment to the ladle furnaces enabled ladle refining of all the heats. It is possible today to manufacture a superclean ingot which contains extremely low impurities and weighs as heavy as 600 tons. As secondary refining equipment by remelting, an ESR (Electro-Slag Remelting) furnace with capacity of 20 tons was installed in 1963 and was used for manufacturing retaining rings and other high alloy steels. In 1992 an ESR furnace with the maximum melting weight of 100 tons was started operation together with a 5 ton VIM installed at the same time.

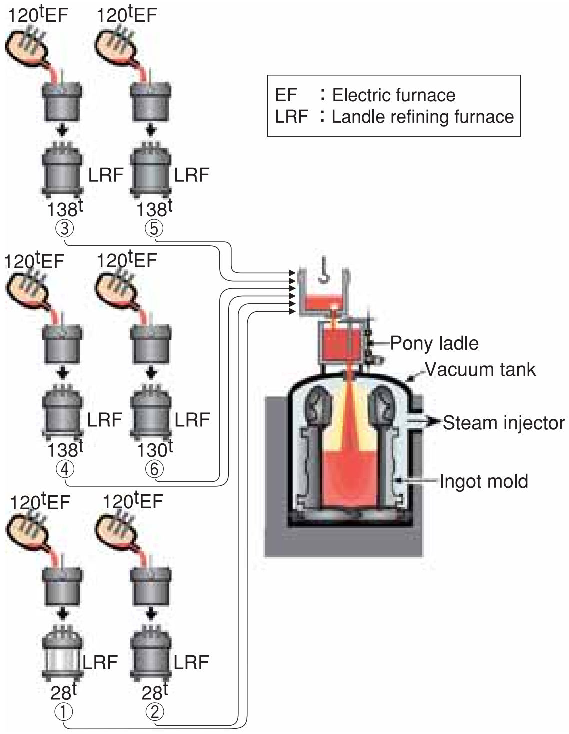


Fig. 1 Schematic diagram of large ingot making by means of multiple pouring.

Forging technologies were developed in order to eliminate coarse solidification structures of large ingots by means of high temperature diffusion and plastic deformation as well as to attain integrity of internal properties by consolidation of porosity formed during solidification. The warm forging (called JTS process) developed in 1959 was a method to cool a uniformly heated material before forging so that a temperature difference between the surface and the interior would effect great isostatic compression in the interior due to differences in the flow stress. This process is the basis of forging large ingots and has been continuously improved to date. Recent application of numerical analyses using the finite element method to plastic deformation has made it possible to analyze and quantify conditions for consolidation of porosity in accordance with product shapes. Some of the ring-shaped pressure vessel components, especially for nuclear applications, became too large to be finish-forged inside the press, so that equipment was invented for forging outside the 10,000 ton press (**Photo. 3**).

Photo. 3 Forging operation outside the 10,000 ton press.

Supported by these manufacturing technologies, characteristics, shapes, internal integrity and mechanical properties of products were considerably improved, and new products were delivered into the market. In the field of rotor shafts, monoblock low pressure rotor shafts to replace the shrink fit structure and high pressure/low pressure combination rotor shafts utilizing differential quenching were commercialized. A multiple alloy rotor, for which two heats of steels with different chemical compositions were integrated using ESR, was recently developed. With respect to nuclear components, developments of not only forged rings with large diameters corresponding to the increasing diameter of nuclear reactors but also components with complicated shapes such as flange-integrated heads for reducing weld lines were promoted. As for petroleum refining pressure vessels, V containing enhanced CrMo steels developed in the 1980's changed the concept of pressure vessel steels by petroleum refiners through emphasis on the weight reduction due to smaller wall thickness and on the enhanced resistance to hydrogen caused damages. Clad steel pipes, which are made from clad steel plate by forming and welding, was developed in 1978 and has been delivered since then for transportation of sour crude oil and gas.

Apart from commercial products, JSW has been contributing to the preservation of production technique of Japanese swords as a conventional production technique of high quality steels in Japan since 1918, when it founded a sword shop and began having Japanese sword masters manufacture Japanese swords (**Photo. 4**).

Photo. 4 A scene of Japanese sword shop.

1.2.2 Machinery Products and Their Technologies

(1) Industrial Machinery

Machinery products of the post-war period were dynamically shifted from military to industrial applications owing largely to alliances with foreign manufacturers. As the first attempt, compressor technologies were introduced from Sulzer Brothers (Switzerland) in 1949, and the production was started at Hiroshima Plant. This compressor became principal equipment for chemical plants such as high pressure syntheses of fertilizers and polymerizarion of plastics and was the foothold for JSW to intensively advance to the field of machinery for chemical plants. Thereafter, many machines such as turbo compressors, gas turbines and plunger pumps were introduced from overseas and produced. The oilless reciprocating compressor with labyrinth pistons is still one of the main products today.

In the field of railcar equipment, where JSW had had a base as a supplier since its foundation, the production of couplers and dampers was resumed in 1950 with that of automatic couplers delivered to Japanese National Railways. Blake discs for the bullet train (Shinkansen) and dampers for sleeping cars of limited express were developed later. As for other industrial machinery, hydraulics technology, which had been cultivated through the production of military equipment, was applied to pumps and motors for construction equipment, marine deck cranes and others. While the production of hydraulic equipment has been decreased with changes in the structure of industries, characteristic products such as bolt tensioners for nuclear pressure vessels have been manufactured to date.

(2) Plastic Processing Machinery

Being aware of the growing plastic industry after the war, JSW developed in 1950 a 65mm single screw extruder for wire coating with a hydraulic-driven gearbox, which was said to be the first plastic extruder manufactured in Japan, and started as a supplier of plastic processing machines. The single screw extruder was further developed to be the first domestic extruder for pelletizing polyethylene with a screw diameter of 150mm in 1957. In response to the market demand for screws with larger diameters, a series of single screw extruders with 250 to 460mm screws were developed. Extruders with screws of even 600 to 700mm in diameter have been delivered for pelletizing polyethylene recently.

With respect to twin screw extruders, which have been predominantly applied to pelletizing now, the production at JSW started in 1951 with an intensive mixer for compounding rubber. License of an intermeshed co-rotational twin screw extruder called DSM (Double Screw Mixer) was obtained from Kraus Maffei (Germany) in 1965. Although DSM was manufactured in a large number for compounding PVC and ABS, it was not suitable for large-scale pelletizing and compounding of polyolefin. Therefore, a high speed twin screw mixer CIM (Continuous Intensive Mixer) was developed in 1970, combining excellent mixing capability of the intensive mixer with mixing controllability of DSM, and was delivered as a pelletizing system combined with a single screw extruder for the following stage (**Fig. 2**). Later the system was improved to CMP-X and CIM-P, in which a single screw extruder was replaced with a gear pump, in order to respond to demands for mass production and energy saving mainly with the production of polyolefin.

The uses of twin screw extruders were clearly separated into two major streams in the 1980's, namely, fewer-grades-larger-quantity and wider-grades-smaller-quantity. In order to catch up the latter stream, intermeshed counter-rotational twin screw compounding extruders with long L/D, so-called TEX series, were developed in 1979. TEX series extruders have achieved steady evolution and have established the status of high quality compounding extruders. They demonstrate high performances such as wide applications with flexibility of exchangeable co-/counter rotation directions, applicability to factory automation including the feeding system, improvement in compounding partly due to proprietary design of screws and cylinders and the increased torque. In addition, supporting technologies like simulation analyses of compounding and materials for screws and cylinders have backed up the high performance of TEX series. The ninth generation of TEX-V is

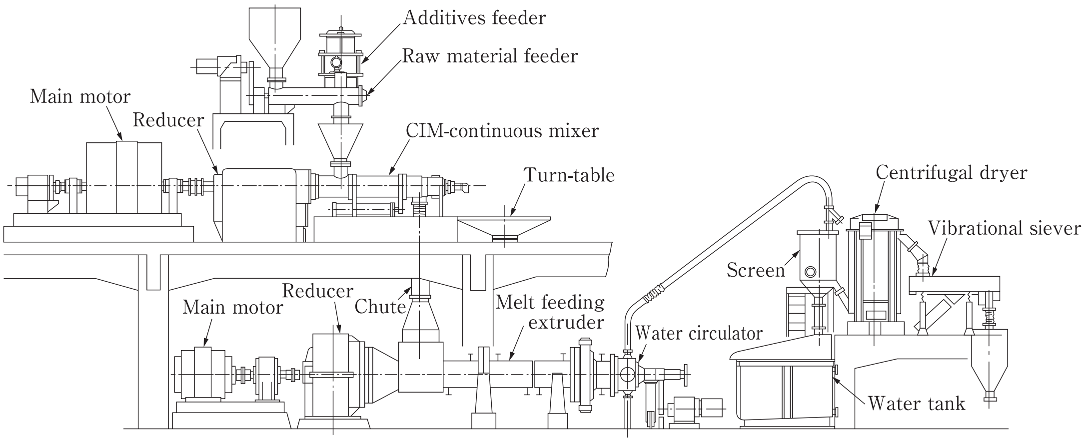


Fig. 2 CIM pelletizing system.

being put into the market now. These twin screw extruders have also been widely applied to devolatilization, reactive processing, food processing and polymerization and recycling of bio-based polylactic acid.

The first film-making equipment with a T-die had been developed since 1955 and was delivered in 1959. Although blown film type equipment was also manufactured at first, the development was gradually shifted to the biaxial-stretching film making system according to the demand in the 1960's for high-performance, high-added-value products such as photographic film. Through cooperative work with domestic resin manufacturers and the introduction of transverse stretching technology using roller clipping devices from Dornier (Germany) in 1970, JSW acquired capability to provide total film production lines from extrusion to biaxial stretching. Since then, developments have been extended to various multi-layered film technologies, controlling technologies such as automatic thickness control, wide T-dies and other technologies. The scope of biaxial-stretching film-making system is now expanding further after the film-making system business was transferred from Mutsubishi Heavy Industries in 2006.

The production of blow molding machines started in 1962, when the technology was introduced from Kautex (Germany), and a blow molding machine with an accumulator was developed in 1968 to enhance adaptability to processing engineering plastics. However, the development was switched to original design of new machines in the 1970's so as to satisfy the strict quality requirements mainly due to Japanese regulations on food containers like soy sauce bottles. Advancement of blow molding machines were achieved by installing an automatic parison thickness controller and a man-machine dialogue type controlling system. Small- to medium-sized machines were all shifted to electric servo-motor driven in the 1990's. Large-sized machines were oriented to be capable of multi-layer molding, targeting plastic fuel tanks for automobiles which were put into production in the 1980's. A blow molding machine for 4-grade-6-layer fuel tanks was commercialized in 1998, and it has been delivered to inside and outside Japan (**Photo. 5**).

Photo. 5 Large-sized blow molding machine for plastic fuel tanks.

(3) Plastic Injection Molding Machines

The production of plastic injection molding machines started with the acquisition of technology licenses of screw in-line injection molding machines from Ankerwerk (Germany) for toggle joint clamping forces of 30 to 350 tons (1961) and from Kraus Maffei (Germany) for direct clamping forces of 580 to 1,150 tons (1963). Machines were gradually lined up from small to large sizes.

In the 1970's, small- and medium-sized machines for machinery and optical parts were required to possess high productivity and high dimensional accuracy, therefore, developments such as hydraulic motor driven screws and multi-stepwise pressure control were carried out for improved precision and high molding cycles. As plastics were more widely applied to thin-wall parts such as compact discs and personal computer panels in the 1980's, even higher precision and productivity were demanded. Based on confidence that dimensional accuracy of molded parts were closely dependent of overall conditions of injection molding, JSW responded to these demands with the optimization of clamping unit, check ring and screw configuration, the improvement in pressure control on high speed injection, the development of injection-compression molding and other developments. For accurate and easy process control, the control panel was furnished with man-machine interfaces, and reliability of the control system was improved by the reduction in the number of electronic parts through applying a surface mounting method and custom IC technology. Furthermore, progress in controlling software enabled the installation of expert system. These controlling techniques became widely used in combination with the appearance of electric servo-motor driven injection molding machines in place of hydraulic driven ones. Scale-up of electrically driven injection molding machines has gradually proceeded last 20 years since JSW delivered the first electric servo-motor driven machine in 1987, and has reached as large as 2,500 ton clamping force now.

With respect to the process technology, various hybridized injection molding processes as follows have been developed. In the sandwich molding, the skin and the core layers are separately injected. The near-net-shape molding of ceramics and metal powders consists of compounding these inorganic materials with binding resin before molding, de-waxing after molding and sintering to form solid inorganic parts with complex shapes. Resin bonded magnets are made by injection molding a compound of magnetic powder and resin under a magnetic field. Foaming during molding using supercritical carbon dioxide has been also developed. Among these hybridized processes, most notable is the DSI (Die Slide Injection) process, in which hollow parts can be molded by sliding the die between a plural number of injection, because it can contribute not only to cost reduction but also to improved functions of molded parts. The DSI process has indeed created many applications.

It should be mentioned that the technical innovations with plastic machinery have largely owed to Machinery Reasearch Laboratory, which was established in 1975 and Technical Development Center (**Photo. 6**) established in 1991, both inside Hiroshima Plant. At Machinery Reasearch Laboratory structural materials with high corrosion resistance to plastics containing F, Cl and S and/or with high wear resistance to plastics with hard fillers like inorganic particles and glass fibers have been continuously studied. The above-mentioned ceramics near-net-shape molding and bonded magnet molding could not have been commercialized without these materials developments. The development of control systems for injection molding machines used to be carried out at Machinery Research Laboratory although the staffs have moved to the Injection Molding Machinery Division together with their accomplishments. At Technical Development Center, which is furnished with a single screw extruder with variable screws and cylinders, 13 twin screw extruders, a biaxial stretching film-making system and more than 20 injection molding machines, not only the development of new processes but also test runs requested by customers have been carried out for extrusion, compounding, devolatilization, film stretching and injection molding. These test runs are, on one side, the resource of creating new processes and new machines that are ahead of market needs of the era.

Photo. 6 Technical Development Center (Hiroshima).

1.3 Developments in the New Technology Field

As an integrated manufacturer of steels and machinery, JSW considerably increased its sales during the economic growth in the 1960's to the early 1970's. However, the main products, both steels and machinery, depend strongly on capital investment in the energy industry, and thus the sales and profits were largely controlled by business fluctuation in the energy sector. This negative aspect became more distinct after the first oil crisis in the 1970's. Since then expectations to the development of new products in new business fields have been always high in the corporate.

Development of a baby cyclotron for medical applications, which started in 1972 as joint work between The Institute of Physical & Chemical Research (RIKEN) and Muroran Plant was an example of such attempts to new products. After the first commercial system was delivered in 1978, orders mainly from research institutes were repeatedly acquired by JSW as the pioneer of small-scale cyclotrons. Although the cyclotron was ultimately withdrawn from the market due to lack of profitability, this development left behind technology of controlling electron-charged particles and plasma and of vacuum equipment.

In the 1980's a full-automatic guide-hole drilling machine for multilayer printed circuit boards and a full-automatic printed circuit board punching system were developed at Machinery Research Laboratory as JSW's first electronics equipment. Especially the guide-hole drilling machine won the top share with selling points of operability, high speed and high precision. Although the production was terminated in the 1990's because of changes in market needs associated with a technical innovation of printed circuit boards, these products built up a step toward the electronics industry.

In order to conduct such research and development for new technology fields thoroughly and systematically, Tokyo Research Laboratory was established in Fuchu, Tokyo in 1986. It was moved to Yotsukaido, Chiba and renamed as Research Center for Advanced Technologies three years later. Creation of new products in new business fields totally different from those of JSW's exiting businesses was targeted at this laboratory. So, typically research on new materials such as functional ceramics, thin films, powder metallurgy and oxide single crystals and developments of optical devices and vacuum equipment including an ion etching system and an ion implantation system were carried out. Investment was especially concentrated on the development of products that aimed at so-called opto-electronics field. However, the depression caused by the burst of bubble economy took place before the anticipated results would be accomplished. The orientation of research and development was thus changed toward the field where JSW's core technologies could be effectively utilized. As the result, a couple of new products were successfully developed, and they eventually opened a door to a new business field, i.e., production systems for IT (information technology) appliances. One was the magnesium injection molding machine, to which Thixomolding®, an injection molding process for semi-solid magnesium alloys introduced from Thixomat (U.S.A.), had been applied. The other was the excimer laser annealing system installing an excimer laser head manufactured by Lambda Physik (Germany) for the low temperature poly-crystalline Si films used for TFT-LCD (thin film transistors for a liquid crystal display).

Commercialization of magnesium injection molding machine was truly pioneer work among the licensees of Thixomolding® because in addition to the inherent technology of plastic injection molding machines, proprietary materials engineering of Muroran Plant was effectively applied to prepare the structural components that must withstand high temperature above 600℃ of half molten magnesium alloys. Since it was just in time, when the production of light weight housings for notebook personal computers and cellular phones was about to boost, orders for the magnesium injection molding machine increased very rapidly, which led to the foundation of Magnesium Process Equipment & Products Division in 1997. The excimer laser annealing system underwent similar progress. When the system was commercialized using self-developed transport mechanism, vacuum components and control system, active capital investments on the production line of high mobility TFT's were started in the display industry in response to the market demands for portable LCD with high definition. Thus, the laser annealing system rapidly grew up to be one of the main products of Yokohama Plant and once even surpassed the blow molding machines which had been the traditional main product of the plant. Research Center for Advanced Technologies was moved to inside Yokohama Plant in 2000 and was re-organized as a branch of Machinery Research Laboratory. It is now the base for IT-related research and development together with IT R&D Center established in 2007.

2. Today's Characteristic Products and Technology

2.1 Materials

2.1.1 Steel Making

(1) Production of Invar Alloy for Shadowmask Application

Shadowmask used for a computer display, is a key component which affects definition in images, and 36%Ni alloy called invar which has very low thermal expansion coefficient is used for the application. Low thermal expansion of invar alloy is deteriorated by small amounts of impurity elements. Besides, the shadowmask material is cold rolled down to 130μm thick and subsequently undergoes etching to obtain an array of precisely shaped holes of 120 - 200μm in diameter, therefore, non-metallic inclusions in the material must be reduced to the extreme. Consequently, production technology of metals with high purity and cleanliness far beyond the current commercial level is required for invar alloy.

Development of invar alloy was started with a study on melting a high purity alloy, then shifted to a development of high cleanliness ingot making by bottom pouring method, and moreover, to a development of solidification structure control due to a requirement for low Ni segregation in the product. Based on the results, the alloy was commercialized as an electronic material, and the mass production was started. There were many unresolved issues in production at the beginning. However, a project team organized with Nippon Mining & Metals finally succeeded in establishing a stable production process of high purity invar alloy using JSW's melting facilities through establishment of stable melting, improvement in melting control, optimization of slag composition, and sophistication of inclusion control. The effort provided a good opportunity to radically review JSW's conventional melting and ingot casting technologies, and this led to enhancement of high purity and cleanness of the ingot. The developed technologies through the invar alloy production have been applied not only to electronic materials but also to various products such as generator materials and thus the development showed good ripple effects.

(2) Development of Multiple Alloy Rotor Shaft

Multiple alloy rotor (MAR) shaft forging for single-flow, intermediate-low-pressure-integrated steam turbines is made of an ingot consisting of two different steels, which have been jointed together with ESR. It is composed of a CrMoV steel for the intermediate pressure (IP) section and a NiCrMoV steel for the low pressure (LP) section. Because an MAR shaft enables to put turbine blades in the joint section, unlike other jointed rotor shafts such as a welded rotor shaft, downsizing of the shaft and enhancement of energy efficiency are expected.

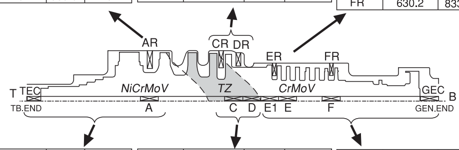
The CrMoV- and NiCrMoV steel electrodes were made separately by a conventional basic electric furnace melting process followed by ladle refining. The ingots were forged to an electrode shape, and the two electrodes were welded together to form a single ESR electrode. The electrode was then ESR melted using a mold of 1800mm in diameter to produce a multi-alloy ingot. In order to obtain a sound and axi-symmetric chemical transition zone required for turbine rotor applications, an improved ESR process and special forging techniques were developed. Also, an optimized differential heat treatment for the two chemistries with a transition zone and a non-destructive measuring method of the dimension and location of transition zone were developed. Longitudinal distribution of Ni content in the center core of the forging revealed that the chemical transition zone began at about 2500mm from the generator end and that the Ni content reached 3.5% at about 3500mm from the generator end. **Table. 1** shows mechanical properties of the body and center core, which confirms that both IP and LP sections possess equivalent properties to those of monoblock CrMoV- and NiCrMoV steel rotor shafts, respectively. All test coupons met property requirements. The assembled MAR is shown in **Photo. 7**. This development was performed in cooperation with GE Energy (U.S.A.).

Table. 1 Mechanical properties of a multiple alloy rotor shaft at various locations.

NiCrMoV	0.02%P.S. MPa	T.S. MPa	FATT, K
AR	715.7	869.5	248.2

TZ	0.02%P.S. MPa	T.S. MPa	FATT, K
CR	675.0	831.5	305.9
DR	627.4	798.4	310.4

CrMoV	0.02%P.S. MPa	T.S. MPa	FATT, K
ER	645.4	833.6	382.0
FR	630.2	833.6	378.2



NiCrMoV	0.02%P.S. MPa	T.S. MPa	FATT, K
TEC	730.2	881.2	—
A	719.8	883.2	227.0

TZ	0.02%P.S. MPa	T.S. MPa	FATT, K
C	593.0	775.7	262.0
D	570.2	769.5	313.2

CrMoV	0.02%P.S. MPa	T.S. MPa	FATT, K
E1	632.3	836.4	385.9
E	625.4	835.0	387.0
F	623.3	830.2	388.2
GEC	623.3	832.9	—

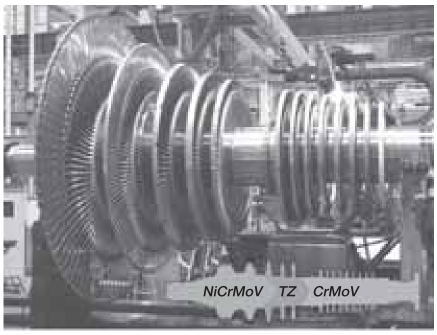


Photo. 7 Assembled multiple alloy rotor.

2.1.2 Product Manufacturing

(1) Nuclear Pressure Vessel Components

JSW has developed integrated-type monoblock forged components for nuclear reactor pressure vessels, by which significant advantages could be obtained such as enhanced reliability, improved economy and reduction of the fabrication period of pressure vessels compared with those made by plate construction. Responding to the demands for enlargement of the components, increased power generation capacity of power plants and advanced reliability, such production technologies have been established as casting technology of huge ingots up to 600ton, refining technology through a double degassing process to attain high purity and cleanliness and forging technology for components of large and/or complicated dimensions as well as for large stainless steel components. At present, not only the nuclear pressure vessel but also shells and heads of the steam generator can be fabricated using monoblock forged components. For example, bottom petal of advanced BWR was first manufactured from a 600 ton ingot. Recently, integrated forging of nozzle shell with flanges was successfully manufactured from a 600 ton ingot for 1600MW European pressurized water reactor at Olukiloto #5 Power Plant (Finland). Intensive examinations on the mechanical properties and homogeneity of the chemistry confirmed excellent performance of the forging. Further developments of advanced integrated forgings and their production technologies have been continuing, aiming at the fast breeder reactor (FBR) and the high temperature gas cooled reactor (HTGR).

(2) Pressure Vessels for Petroleum Refining

With respect to the pressure vessels for petroleum refining, which are used under high temperature, high pressure hydrogen environments, materials have been developed to meet the demands for enlargement of pressure vessels and increases in temperature and pressure in the process. Nowadays, enhanced CrMo steels developed in the NEDO (New Energy and Industrial Technology Development Organization) project of direct coal liquefaction and in the MPC/API project in the U.S.A. have been extensively used for the pressure vessels in oil refinery. Enhanced CrMo steels have superior mechanical properties and low hydrogen embrittlement sensitivity. Application of state-of-the-arts steel refining technology has made it possible to attain excellent resistance to long-term degradation such as temper embrittlement. The 3CrMoVTiB steel developed by JSW was authorized as ASME material SA336 F3V and first used for reactors of Husky Oil (Canada), which were commenced the commercial operation in 1992. Furthermore, the 2 1/4CrMoVTiB steel was developed and authorized for the application up to 900F (482℃) in ASME Code Sect.VIII Div.II, which has become the principal material of hydrogenation reactor pressure vessels for current petroleum refining.

(3) Clad Steel Pipes

The natural gas has drawn close attention worldwide as clean energy with low emission of carbon dioxide compared with coal and oil. The market of clad steel pipes has widely grown in recent years because the clad CRA (Corrosion Resistant Alloy) such as stainless steels and Ni base alloys exhibit excellent corrosion resistance against untreated sour gas. Clad steel pipes are manufactured using clad steel plates made by a hot rolling process. After machining of longitudinal weld bevel and cold forming into a cylindrical shape by a press, longitudinal seam is welded from both inside and outside. On the welding of clad steel, dissimilar metal welding is carried out from the CRA side. Welding conditions and the consumable have to be carefully selected because the same corrosion resistance as CRA is required for the weld surface. Recently JSW has developed API-5L grade clad steel plates with high strength that can satisfy the impact toughness requirement at -40℃ as well including the weld heat affected zone.

2.1.3 Equipment Diagnosis

It has been more than 40years since JSW started manufacturing heavy gage reactors for the oil industry. Reactor pressure vessels made in early days have been still operated under aggressive temperature and pressure environments, and some of the aged reactors are found damaged due to long-term degradation. Typical damages are temper embrittlement, hydrogen embrittlement, disbonding of stainless weld overlay and hydrogen attack. For the safe operation of aged reactors, it is important to evaluate the degree of damage and to conduct safety analyses and the assessment of remaining life. JSW has investigated aged reactor pressure vessels in cooperation with many refinery users. Based on these results, developments in the maintenance technique have been carried out, and methodologies for safety evaluation have been established.

Safety analysis system of equipment has been developed based on the accumulated knowledge on these material degradations and damages of the aged reactors. This safety analysis system consists of i) estimating method of the degree of temper embrittlment in terms of the chemical composition of steels and the operating conditions of reactors, ii) estimating method of the transition behavior of fracture toughness using material testing data obtained according to the industrial standard and iii) the database of threshold stress intensity factor for hydrogen assisted crack growth K_{IH}, and others, and could be operated on the internet.

This system has been used to provide safety analysis results to the clients such as the determination of minimum pressurization temperature of pressure vessels. The flow chart of safety analysis against hydrogen embrittlement is shown in **Fig. 3** as an example.

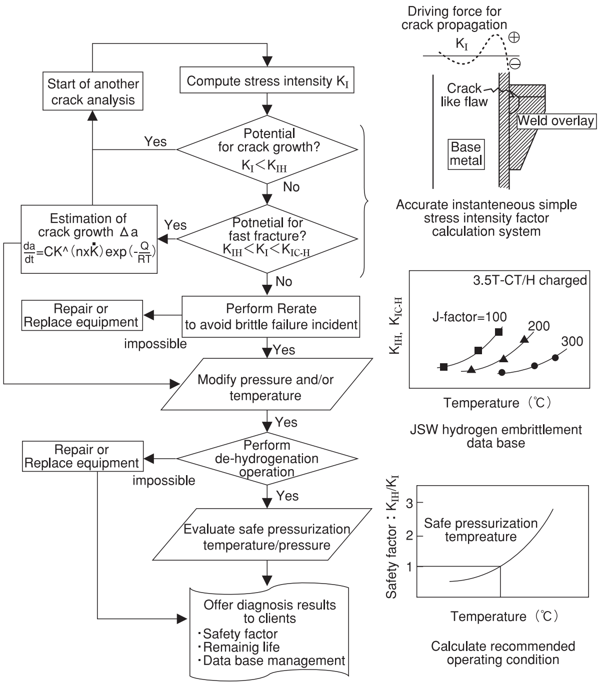


Fig. 3 Flow chart of safety analysis against hydrogen embrittlement.

2.2 Machinery

2.2.1 Corrosion- and Wear Resistant Materials

Cylinders and screws of extruders were originally surface-hardened with nitriding for preventing troubles during operation caused by wear and corrosion. In order to strengthen their wear-resistant properties, a centrifugal casting process was introduced from Xaloy (U.S.A.) in 1968, by which cylinders of single screw extruders were lined with a few mm thick hard facing alloy such as high Cr cast iron or NiCo alloys.

In 1978 the lining technology of Ni-based hard facing alloys, named N-alloy, was self-developed by JSW for the cylinders of injection molding machines, combining a vacuum melting process with the centrifugal casting process. This alloy lining had been continuously improved, and consequently, a supreme wear-resistant WC composite alloy, named N2000F, was developed and its mass-production system was established under stable quality control.

Furthermore, the seamless lining of cylinders for twin screw extruders, shown in **Photo. 8** should be noted. Since it is not possible to apply centrifugal casting to these cylinders, a lining process, called JPM, comprising powder metallurgy, vacuum melting and directional solidification, was developed by the proprietary know-how. This process has become applicable to cylinders for TEX305 or smaller extruders.

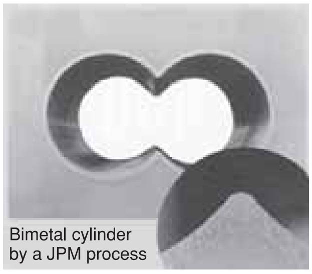


Photo. 8 Seamless lining of a cylinder for a twin screw extruder (JPM process).

As for screws, a molten and refined wear-resistant steel, called LS2, which was improved from a cold work tool steel, was developed from 1981 to 1983 in a collaboration with Muroran Research Laboratory and was adopted for screws of both compounding extruders and injection molding machines. Today, a hot isostatically pressed (HIP'ed) and hot rolled tool steel, renamed LSP-2, has been used as the standard wear-resistant grade together with a HIP'ed high-speed steel, called LSP-H, as a highly anti-wear grade, and a HIP'ed high Cr stainless steel, called LSP-4, as a high wear- and corrosion-resistant grade, according to various specifications of these machines,.

2.2.2 Plastics Flow Simulation

In 1968, a laboratory for plastics research was established at Hiroshima Plant, where the research was carried out on flow analysis and simulation of plasticizing behavior with shear stresses in single- and twin screw compounding extruders, controlling molecular weight distributions and melt indices, and reactive processing combining chemical reactions with mixing extrusion.

Especially, in flow simulations of plasticizing behavior, international exchanges of knowledge were proceeded through the participation in the research project "Polymer Mixing Study" at Stevens Institute of Technology (U.S.A.) in 1979. As the result, a proprietary simulation technique of JSW has been realized, so that highly accurate analyses of polymer pressure, temperature and filling rate in combinations of various screw elements are possible as flow behavior of polymer fluids in twin screw extruders (**Fig. 4**). This has been commercialized as a simulation software, named TEX-FAN.

Fig. 4 Marker-particle tracing unsteady analysis in a 3D model.

In the devolatilizing technology, the techniques of surface-renewal devolatilizing and water-injection foaming devolatilizing were accomplished based on theoretical analyses and experiments. The delivery experiences of the large-size twin screw extruders with superior performance in devolatilizing increased to make JSW's position in the plastic industries firm, and this achievement won "The Katashi Aoki Technology Award" granted from the Japan Society of Polymer Processing in 1994.

As for the plastic flow analysis in the injection molding, the development of simulation software about mold filling analysis, pressure holding and cooling analysis, mold cooling analysis, warpage analysis, residual stress (or birefringence) analysis and plastic crystallization analysis for the injection molding process was carried out through the participation in the PDC Consortium (consisted of Mitsui & Co., Ltd., Mitsui Chemicals, Inc., Kaneka Corporation, DENKA, Sekisui Chemical Co., Ltd., Kozo Keikaku Engineering Inc., Plamedia Corp. and JSW) during the period from 1988 to 2002. The simulation results were compared with the results of molding tests and sample measurements, and the flow simulation software in the injection molding process has been commercialized as the computer-aided engineering software, PLANETS.

2.2.3 Polymer Foaming and Compounding with Use of Supercritical Fluid (SCF)

A technology to produce micro cellular foaming sheets from used PET (Polyethylene Terephthalate) bottles by extrusion using super critical carbon dioxide as a foaming agent was developed in cooperation with Dainippon Ink and Chemical Inc. with the subsidy of NEDO in 1999. This technology is to obtain the foamed sheet which containing bubbles partially below 100μm in diameter, using a tandem system consisting of an upstream twin-screw extruder that is good for reactive extrusion and devolatilization and a downstream single-screw extruder, in which the former vaporizes water in plastic and promotes cross-linking and an increase in viscosity of used-PET, while the latter dissolves SCF, cools the resin and forms the sheet.

While marketing of this foamed sheet production system was promoted, Machinery Research Laboratory began the research on the application of supercritical carbon dioxide to compounding, reactions and devolatilizing processes of molten polymer in 2000. The evaluation of effects of SCF on plasticizing and enhanced compatible solubility and the optimization of process conditions were carried out through test runs requested by customers. As the result, effects have been confirmed as increased reaction rates in polymer cross-linking and other processes, improved dispersion capability in polymer alloying processes and improved devolatilizing capability, and these effects were partly issued as patents jointly applied with the customers. The fundamental system of SCF application using a twin-screw extruder is shown in **Fig. 5**.

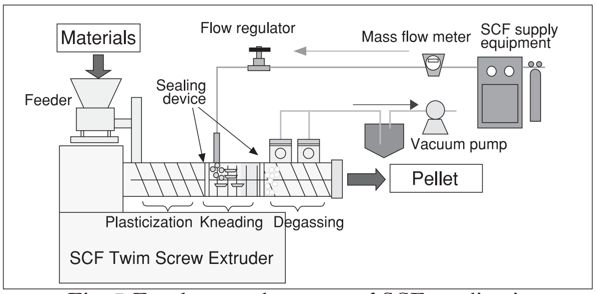


Fig. 5 Fundamental system of SCF application using a twin-screw extruder.

2.3 New Technology Field

2.3.1 Metal Hydride

Since 1979 various hydrogen absorbing alloys and their application systems have been developed at Muroran Research Laboratory.

On the early stage of development, so-called AB_5 type CaNiMmAl alloys (Mm: misch metal, mixture of rare earth metals such as La and Ce), which have the same structure as a $LaNi_5$ alloy but do not contain expensive La, were successfully developed and applied to hydrogen storage tanks, heat pump systems for recovering waste heat and hydrogen purification systems. The hydrogen purification systems were developed in a collaboration with an electric power company and an electrical equipment manufacturer in order to maintain the purity of hydrogen contained in the power generator as a coolant and are still in operation at several power stations. TiZrCrFeMnCu alloys and TiZrMnVFe alloys, which are AB_2 type Laves phase alloys and show greater hydrogen storage capacity, were also developed and applied to the co-generation system using waste heat of the micro gas turbine. This co-generation system combined with a desiccant air conditioner was delivered to a supermarket.

Hydrogen storage tanks containing hydrogen absorbing alloys (**Photo. 9**) have been drawing interest since 1998 as a hydrogen source for the fuel cell. The hydrogen storage tanks for rapid charging and discharging of hydrogen with efficient heat exchanging channels made of aluminum fins were supplied to the automobile industry and gas companies. A large hydrogen storage tank with hydrogen storage capacity over 100 Nm^3 was loaded by URASHIMA, an autonomous deep-sea exploration robot developed by Japan Agency for Marine-Earth Science and Technology, in 2003. URASHIMA accomplished the world-record, a 317-km of continuous cruise driven by a fuel cell system, on February 28, 2005, which was awarded a special prize of the 34th Grand Prix for Japanese Industrial Technology. Recently, the micro tanks with hydrogen storage capacity from several to a dozen liters have been developed for fuel cell powered portable electronic appliances like a cellular phone. The development of alloys with higher storage capacity has been continued to improve the hydrogen storage density of the tanks. Rechargeable hydrogen storage capacity of TiCrV alloys with a crystal structure of body centered cubic has reached 2.5 mass%, the highest value among the practical hydrogen absorbing alloys. The development of novel Mg-based and Ca-based alloys for higher hydrogen storage capacity is also underway.

Photo.9 Hydrogen storage canisters and micro tanks containing hydrogen absorbing alloys.

2.3.2 Magnesium Injection Molding Machine

Thixomolding® process developed by Dow Chemical (U.S.A.) is the technique to injection-mold semi-molten magnesium alloys stirred with a screw.

When this process was introduced and the development of the commercial machine and production system was started in 1992, there were many unsolved subjects. Especially, characterization of internal properties of molded magnesium alloys, machine design for high-speed injection molding and rigidity at elevated temperatures and selections of structural materials resisting corrosion due to the molten alloys were important issues for this special injection molding process.

In order to solve these problems, the experts' knowledge in the entire company was gathered in Hiroshima under the cooperation between Magnesium Process Equipment & Products Division, newly established in 1997, and Research & Development Headquarters. Especially R&D Headquarters endeavored to develop heat-resistant materials, and as the results HIP'ed bimetal cylinders and PTA (Plasma Transferred Arc) welded screws were applied to commercial machines. Thereafter a heat-resistant material developed at Muroran Research Laboratory has become the standard material for the cylinders.

Supported by these developments, magnesium injection molding machines have been served in industrial fields of household electric appliances, personal computers and cellular phones, and further growth is expected in the expanding Asian market.

2.3.3 Excimer Laser Annealing System

Recently flat-panel displays have not only replaced CRT-TV sets but also been installed in the many kinds of electronic appliances such as cellular phones, digital cameras, personal computers and car navigation systems. These displays, which are mainly color liquid crystal displays driven by TFT (Thin Film Transistor), are required to show high resolution, high luminosity and quick response, so that the semiconductor in TFT switching devices has shifted from amorphous silicon to poly-crystalline silicon. Since the production of poly-silicon film needed thermal annealing, glass substrates could not be used except quartz glass ones in the past.

JSW developed a low temperature crystallization process utilizing excimer laser annealing, in which ordinary glass substrates with a low melting point could be treated, and commercialized a laser annealing system applicable to the panel production line in 1995 for the first time in the world. For the next ten years, approximately a hundred annealing systems were delivered to major manufacturers of the liquid crystal panel inside and outside Japan to receive favorable reputation from them. Under the recent situation where even higher performances are increasingly required to those panels, a new annealing system with low manufacturing- and running costs and easier maintenance has been developed utilizing solid state laser.

2.3.4 Waste Plastics Recycling System

The equipment for dehydrochlorination of waste plastics and manufacturing RPF (Refuse Paper & Plastic Fuel) using a twin screw extruder was developed through the participation in the research projects of "Commercial viability of the reproduction plastic processing fuel making technology and the adjust-ment fuel technology" funded by the Ministry of International Trade and Industry and "Industrial technology promotion project for global environmental preservation" by the Research Institute of Innovative Technology for the Earth (RITE) in 1996 through 2001.

This technology is to remove harmful chlorine, which would cause corrosion of the incinerator materials and generation of dioxin, from collected waste plastics prior to producing RPF, and the equipment achieved the total chlorine content of 0.1% remaining in general waste plastics.

Moreover in 2002, application of the technology was studied with industrial waste plastics containing high-concentrate polyvinyl chloride (PVC) in a collaboration with the Polyvinyl Industry and Environmental Council. **Photo. 10** shows the first practical machine, a small-scale dehydrochlorination system using TEX196D produced in 2002.

As the result of these developments, the first order for a commercial dehydrochlorination system was acquired in 2003 for recycling waste plastics collected from plastic packaging to the carbon source for blast furnaces, and the operation was started in 2004. For the delivery of commercial system and the development of dehydrochlorination technology, the "Award for Technological Distinguished Service" was granted from Research

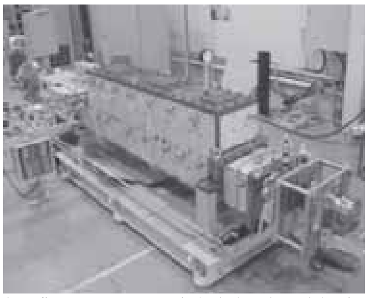


Photo. 10 The first commercial dehydrochlorination system, TEX196D (Output: 120kg/h).

Association for Feedstock Recycling of Plastics, Japan (FSRJ) in 2005. It was followed by the second order for a commercial dehydrochlorination system in 2006.

Moreover, the technology was developed to apply to the volume reduction of waste plastics into high-density pellets based on the melting equipment of the dehydrochlorination system. The first order for a commercial system was acquired in 2004, and the operation was started a year later. The demand for this system is expected to increase in the near future.

3. Approaches to the Future

The perspective of JSW on the future is to expand the present business that has delivered many products to the market after the war as "an integrated manufacturer of steels and machinery" as well as to extend the emerging business such as information technology related equipment so that it could become "an integrated manufacturer of materials and mechatronics (mechanics & electronics)". In other words, JSW is going to develop the enterprise on the basis of its footing businesses through making current profitable products more competent as a fundamental approach and adding extended lineups of the products. Moreover, on the foundation of traditionally cultivated technologies, JSW is going to develop new products and to create new businesses, which will sustain the company in the coming era.

In the two categories of the current and extended products, i.e., the materials sector for mainly energy-related structural and machinery components and the machinery sector with plastic processing machines and other industrial machines, priority will be placed on the development and advancement of inherent technologies from a viewpoint of improved quality and performance, on the competence strengthening and on the maintaining the world's top shares.

In the materials sector, it is foreseen that the business of petroleum refining pressure vessels will expand due to the increasing worldwide demands for energy and the high level of oil price. Increasing consumption of natural gas due to the attention to the global warming will enlarge the clad pipes business. Furthermore, the nuclear components business is also foreseen to drastically grow as the world's energy demand is shifting along with so-called nuclear renaissance. Therefore, not only the quality enhancement of energy-related products and the process advancement including production facilities, but also the process innovation for strengthened product competence through cost reductions will be strongly promoted. As for other materials, advanced functional materials should be developed for the extension of materials business in view of a sophisticated era in the near future. In medium to long terms, the steam temperature of power generation will become higher for improved efficiency, and the development of heat resistant materials has already been in progress aiming at the steam temperature of 700℃. In the field of nuclear components, the development of materials for new types of reactors such as FBR and HTGR has been started. These medium- to long-term subjects are regarded in the line of current and extended products and will be proceeded as development of both materials and manufacturing technology.

In the machinery sector, capacity and productivity of plastic processing machines such as extruders and pelletizers have been required to increase year after year, which has demanded higher strength of the structural materials and sophisticated machine design. It is therefore necessary to pursue the extremity of designing in collaboration with materials engineering largely owing to the engineers in Muroran so that JSW's position of integrated manufacturer of plastic processing machines could stay firm. Since it is expected that the growth of automobile industry and the demand for light weight parts or recycling of home electric appliances all lead to increased uses of light metal molding machines, strategic development and/or M&A should be taken for business expansion with magnesium injection molding machines. Other machinery products and components should also be cultivated to become top-ranked in the world as many as possible. Quality enhancement and cost competitiveness are important issues with the machinery products. In light of the global technology race, unification of intellectual property strategy, which is a basis of technology strategy, and business strategy should be actively promoted so that with clear development goals, products fitting the market needs could always be delivered.

In regard to the development of new products and the promotion of new businesses, drastic changes due to advancement of technologies are remarkable in the relatively close fields to JSW such as energy, environments, machinery and information technology. This means that the development of new products and new businesses is quite critical to the company's future and that strategic action should be taken under an incorporated framework of development. Namely on the basis of management of technology, collaborations between the business divisions should be tightened, the potential of inherent technologies with materials and machinery should be demonstrated at the maximum, and timely developments of new products and new businesses should be explored, as was done on the commercialization stage of magnesium injection molding machines and excimer laser annealing systems. Alliances with national and international universities and public research institutes during the developments should also be utilized. We have selected five technological fields on which JSW will focus in the near future out of eight important technological fields that the Cabinet Office of Japan assigned. They are namely (i) new energy, (ii) information and communication, (iii) environment, (iv) nanotechnology and materials and (v) manufacturing technology. Meanwhile, the use of natural energy and renewable energy will be more and more encouraged by the recognition of the global environmental problem. Therefore, wind energy business that JSW is actively setting forward will be steadily grown up and expanded. Hydrogen energy related business will also be incubated as a longer-term project for new energy in the future.

For the last hundred years, JSW has delivered many products as it has put continuing efforts on technological developments and advancements. Based on the century of reserves of technology, JSW will continue contribution to the society by presenting new products that meet demands of the era through further sophisticating its technologies, strengthening its groundwork and developing materials and machinery required by the society.

History of Technical Developments in JSW

1910 1920 1930 1940 1950 1960

- '07 JSW founded
- '50 Reestablishment of JSW, Ltd.

Plant & Laboratory

- '11 Muroran Plant start-up
- '11 Muroran Research Laboratory
- '18 Japanese sword shop
- '20 Hiroshima Plant start-up
- '36 Yokohama Plant start-up
- '41 Musashi (Tokyo) Plant
- '6

Steel & Material

- '40 Installation of 10,000 ton hydraulic press
- '41 Installation of 30,000 HP rolling mill
- '50 Clad plate
- '52 Steam turbine rotor shaft forging
- '55 Casing
- '57 60kgf/mm² grade high tensile strength pla
- '59 Warm forging technology (JTS)
- '60 Vacuum casting technology (m
- '61 Steel plate for nuclear reac
- '63 Installation of 20 to
- '65 Pressure v

Defense equipment

- '14 Type41 36cm Naval gun
- '18 Aircraft 100 HP engine
- '21 Type3 40cm naval gun
- '21 Torpedo tube/submarine
- '30 Armor plate
- '33 Type89 Tank
- '38 Aircraft machine gun (7.7-30mm)
- '42 Type97 Tank
- '53 37mm Cartridge case
- '54 57mm Recoilless rifle
- '61 90mm Tank gun/Type61 T
- '62 Model 30 Rocket launc

Industrial machinery

- '46 Nikko standard type ammonia compressor
- '49 Horizontal/vertical type reciprocating compressor technology (intro. fm. S
- '50 Automatic coupler for railcar
- '50 Nation's biggest paper machine
- '58 NCA2,NCB2 type tight lock coupler
- '59 Labyrinth type reciprocating comp (intro. fm. Sul
- '60 Starting gate
- '61 Axial/turbo type compres
- '63 Bowling pinsetter
- '64 All hydraulic p
- '65 Turbo refr
- '66 RD11
- '66 Marine
- '6

Plastics machinery

Extruder & Pelletizer

- '51 65mm single screw extruder for wire coating
- '60 150mm single screw extruder
- '65 Double scr

Twin screw extruder "TEX"

- '51 Intensive mixer for rubber

Film & sheet manufacturing equipment

- '55 Film & sheet production equipment with T-die
- '59 Film processing equipment
- '59 Blown film equipment
- '64 Biaxially-orient

Blow molding machine

- '62 V8 Blow molding mach
- '65 Accumula blow mo

Injection molding machine

- '61 S&M size molding machine
- '63 L size molding ma
- '64 V series

New products

1970 1980 1990 2000 2007

●'92 J-Tower at Fuchu Intelligent Park ●'07 Oosaki Head Office

8 Plastics Laboratory (Hiroshima) ●'86 Tokyo Research Laboratory (Fuchu, Tokyo) ●'00 Yokohama Research Laboratory
●'75 Machinery Research Laboratory (Hiroshima) ●'89 Research Center for Advanced Technologies (Yotsukaido, Chiba) ●'07 Film&Blow Development Center (Hiroshima)
●'91 Technical Development Center (Hiroshima)

●'70 Vacuum carbon deoxidization (VCD) ●'86 High strength CrMoV steel ●'99 Production technology of inver alloy for shadow mask
●'70 Outside press forging technology ●'87 Production 600ton ingot through LRF ●'01 Runner for pumped-storage hydroelectricity
●'70 8,000 ton hydraulic press ●'87 Super clean LP rotor ●'01 High cleanliness tool steels for hot working
●'71 12CrMoVNbTaN rotor forging ●'89 Installation of 3,000ton hydraulic press
●'72 Monoblock LP rotor forging ●'90 Low Si casing for power generation plant ●'02 Multiple alloy rotor shaft forging
te (Welcon-2H) ●'73 Integrated type shell flange for nuclear reactor pressure vessel ●'91 Components for Advanced BWR ●'03 Installation of 14,000ton hydraulic press
●'76 Integrated type forging component for steam generator ●'91 Intensification of 120ton electric arc furnace
echanical booster) ●'78 Clad pipe ●'92 Components for high temperature gas reactor
ctor pressure vessel ●'79 High pressure-low pressure combination rotor forging ●'92 Installation of 100ton ESR, 5ton VIM
on ESR ●'94 Safety analysis system for petrochemical reactor pressure vessels
vessel for petrochemical process ●'85 Stainless steel component for FBR "Monjyu" ●'96 New 12Cr rotor shaft forging
●'69 Multi poring technology ●'97 Production technology for Ni-base superalloys for gas turbine
●'69 Integrated forging component for nuclear steam supply system ●'86 Double degassing method ●'99 2.25Cr-1Mo-V petrochemical reactor pressure vessel
●'70 Vacuum casting technology (steam ejector) ●'86 Advanced 12Cr rotor shaft forging

●'69 35mm L90 Anti-air gun system ●'81 76mm/62 rapid fire gun ●'01 Type99 155mm Self-propelled howitzer
●'85 155mm Field howitzer FH40 ●'05 Mk45 Mod4 5inch/62
Tank ●'89 Type87 35mm Anti-aircraft gun system
her

●'70 Stud tensioner for nuclear reactor vessel ●'96 Cylinder lifting deck crane for frozen freighter
Sulzer) ●'73 Reciprocating compressor with original technology ●'98 Coupler with shock absorber
●'75 G-9 type special gate valve ●'99 Low pressure enclosed frame compressor
●'75 Rapid-biodegradation composting technology ●'02 Special hydrogen compressor technology
●'76 All welded type ball valve (JB-C type) ●'02 Rubber draft gear with viscous damper
pressor technology zer) ●'78 Scoop type composting machine ●'02 Fib Richer micronizing soybeans machine
●'79 Double-construction type rubber draft gear ●'03 Heavy lift deck crane for heavy freighter
●'86 Clad type brake disk for Bullet Train (Shinkansen) ●'05 Coupler for foreign market
sor technology (intro. fm. Sulzer) ●'86 TEX38F twin screw food extruder
machine ●'90 Slim type deck crane for container freighter
power shovel ●'91 Maintenance machinery for horse race course
rigerating compressor technology (intro. fm. Sulzer) ●'94 Folding jib deck crane
type rubber draft gear ●'94 Cargo deck crane for general cargo freighter
e deck crane (intro. fm. Hägglunds) ●'95 Type 95 starting gate machine
8 Stud tensioner technology (intro. fm. Biach) ●'96 Starter stand car for race course
●'69 General purpose stud tensioner ●'99 Obstacle equipment for horse race

rew mixer "DSM" (intro. fm. Krauss Maffei) ●'81 Continuous mixer pump "CMP"
for pelletizing of polyethylene
●'70 Continuous intensive mixer "CIM" ●'99 Microcellular foam sheet extrusion technology with supercritical CO_2
●'79 TEX series ●'94 TEX α series
●'94 Weighing feeders ●'00 TEX400 of the world's largest class
●'00 Technical collaboration with Trexel
●'04 Flow analysis software "TEX-FAN"
●'83 TEX for PET film recycling ●'05 TEX-V series
ted PET film production equipment ●'86 Module oven for transverse direction stretching machine
●'70 Biaxially film stretching technology (intro. fm. Dornier) ●'87 TEX for biaxially oriented film production line ●'06 Film manufacturing business (intro. fm. MHI)
hine technology (intro. fm. Kautex) ●'88 5 layers of 3 materials PFT blow molding machine
tor head type ●'80 Solar energy boom (Extra-large blow molding machine) ●'92 Electrically driven blow molding machine ●'06 Business integration with Tahara
olding machine technology (intro. fm. Kautex) ●'95 Hydraulic/electric hybrid blow molding machine (NEB series)
●'98 6 layers of 4 materials PFT blow molding machine
e technology (intro. fm. Ankerwerk) ●'80 Hydraulic machine J-S series ●'96 Disc molding machine ●'04 High speed J-AD series
chine technology (intro. fm. Krauss Maffei) ●'88 All electric servo drive machine J-EL series ●'07 Ultra large size J2500AD
●'98 Long fiber recovery technology
●'69 Hydraulic machine N series ●'90 DSI molding technology ●'00 MuCell molding technology

Hydrogen storage technology ●'79 Metal hydride (MH) ●'02 High pressure hydrogen compressor for Takamatsu Station
●'88 MH heat pump system
●'03 MH storage tank for "Urashima"

Magnesium injection molding machine ●'92 Thixomolding technology (intro. fm. Thixomat)
●'94 JLM-MG I
●'96 MG Precision Ltd. start-up

Laser Annealing System ●'95 Excimer laser annealing (ELA) system
●'02 SLS method ELA system

Waste plastics recycling technology ●'96 Dehydrochlorination of waste plastics and RPF manufacturing technology
●'04 Dehydrochlorination equipment
●'04 Volume reduction equipment