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Innovative Development of Aluminium Research and Technologies in Japan

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Aluminium industries in Japan have been widely developed for over 110 years and the total demand on aluminium today is over 4 million tons a year. Although the demand on aluminium in Japan is nowadays the 3rd in the world after China and USA, the aluminium consumption per person is still the top. In Japan, a plant for aluminium sheet production was first built in 1898 and wrought aluminium materials have continuously grown since then on. However, the so-called oil-crisis attacked industries twice and unfortunately the smelting had to be almost withdrawn. This forced the Japanese aluminium industries to specialize in rolling, extrusion and casting. The novel technology of anodic coating for aluminium (alumite) was first developed in Japan in 1929. Extra Super Duralumin (ESD) and Honda Duralmine (HD) alloys were also developed in 1936, these alloys are known as extremely high strength alloys and weldable structural alloys. In these days sheets, extrusions and die-cast for transportation, automobiles, buildings and information technologies have been markedly increased in Japan. Thin sheets with large scale coils are required for beverage cans and are increased as the major products. Body panel sheets and heat-exchange fins for automobiles have been also developed. A great effort has been paid to develop extremely high quality and high performance aluminium materials in Japan. Many research projects on the advanced aluminium materials and processing have been performed with well collaboration. The "Super-Aluminium Project", "Nano-Aluminium Project" and "High-Formability Sheets Project" have been successfully performed. The goal of each project was to achieve innovative technologies for ultra fine grains, nanocluster controlled microstructures and high Rankford values (r-values).

Keywords: *Aluminium industries, Alumite, Extra Super Duralumin, Super-aluminium, Nano-aluminium.*

1. Introduction

Aluminium was first introduced to Japan in 1887 as materials, and then the amount of consumption in a year has recently become over 4 million tons through the fundamental research, production technologies and product development of aluminium. On the way to develop the so-called oil-crisis attacked industries twice and unfortunately the smelting had to be almost withdrawn in Japan. The recent world wide economical crisis also gave big influence on the industries, especially automobile industry. The situation, however, has gradually become improved. After the rapid increase and then dramatic withdrawal of the smelting industry, the aluminium industry in Japan is mostly concentrated in the processing productions. Based on the long history of the great effort on the alloy development, production technologies and demand development, high quality materials and products are produced with high efficiency. Although many of the technologies have been historically introduced from advanced countries, a number of original and innovative technologies have been created in Japan. These days, many innovative technologies have been developed with the close collaboration among industries, universities, academic societies and Japan Aluminium Association (JAA). The historical trend of aluminium production technologies and development are hereafter introduced.

2. Trend of the total demand on aluminium in Japan

The total demand of aluminium in Japan has been favorably growing, except in 2009, a year of the world wide economical crisis. Various important technologies and production developments have been carried out during past decades. The trend of the total demand from 1900 in Japan is shown in Fig.1 together with the primary aluminium production in the world [1]. The mainly developed products are also indicated in Fig.1. The total demand increases with year. The products of the aluminium sash, electrolytic condenser, aluminium can and thermal converter are included. The trend of each type of products is shown in Fig.2 for the past 40 years. The ratio of rolled sheets and extruded products is highest followed by die-castings. Fig.3 shows the trend of each type of applications. Aluminium is widely used for automobiles, constructions and cans. Fig.4 shows the trend of rolled sheets and extruded products. The amount of the rolled sheets is almost the same as that of the extruded products, although slightly higher. The amount of the extruded products gradually decreases recently. The products of aluminium die-casting are shown in Fig.5, indicating that the amount favorably increases. The amount in 2009 unfortunately decreases dramatically.

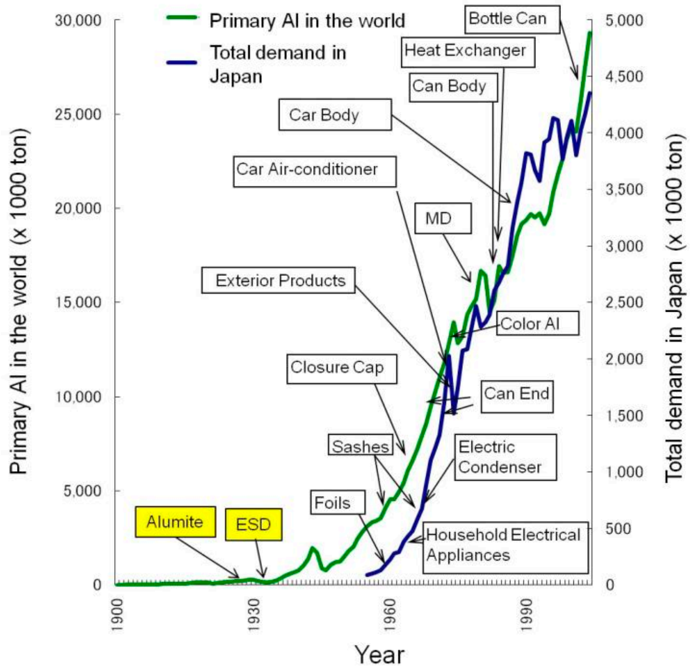

Fig.1 Trend of the total demand on aluminium in Japan together with the primary aluminium production in the world. Some main products are also shown. (courtesy Japan Aluminium Association)

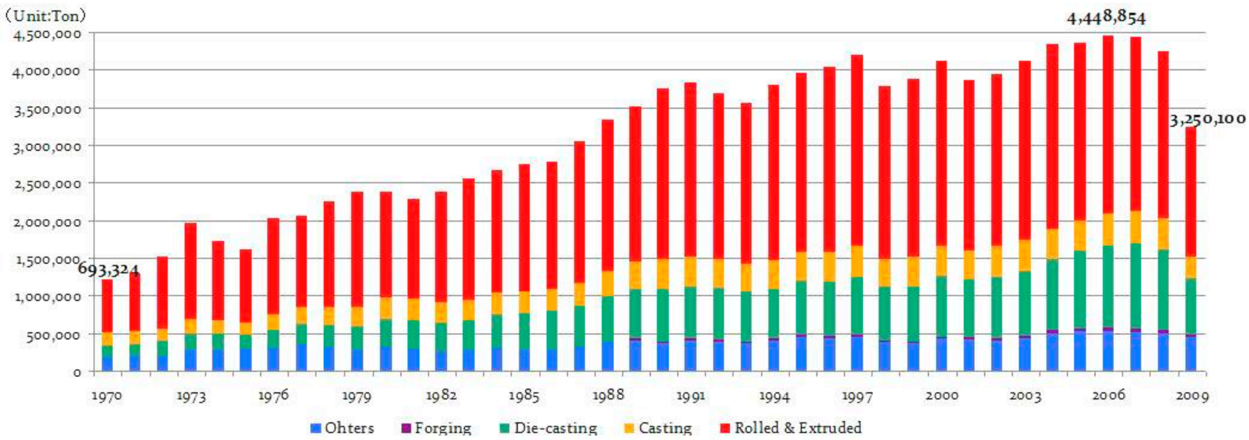

Fig.2 Trend of each type of demand, rolled&extruded, casting, die-casting, forging and others. (courtesy Japan Aluminium Association)

3. Aluminium industries and innovative technologies

3.1 The history of the aluminium industry

The production of aluminium products was started in the next year when the Hall-Héroult process was established in 1886. The aluminium products were first produced at the artillery factory in Osaka in 1894. The products were for the military use. In 1898, aluminium sheets were first produced in a private company, Sumitomo Light Metal Industries Ltd. (present). This was the first start of aluminium industry in Japan. The aluminium was certainly very valuable those days and was called "*the light silver*". On the other hand, a casting industry was started in 1910 and a die-casting industry in 1917. The wire and foil industries were also started almost in the same year. The extrusion industry, however, was not started yet. The brief history of aluminium in Japan is described in Table.1.

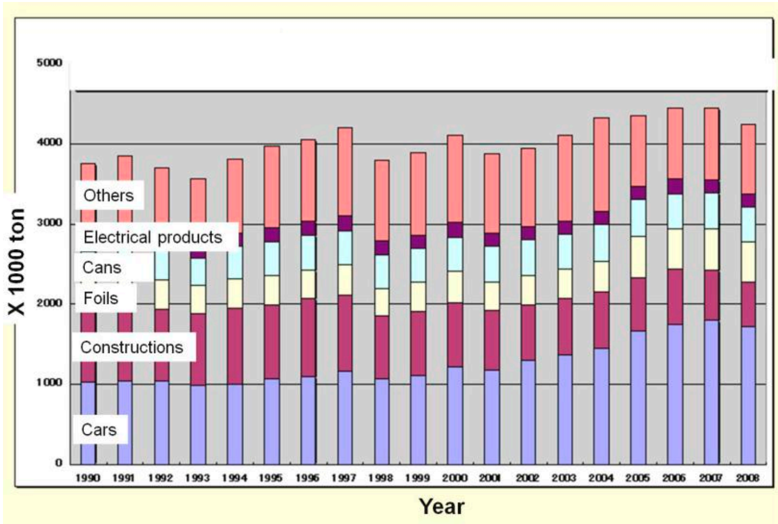

Fig.3 Trend of each type of applications, cars, constructions, foils, cans, electrical products and others. (courtesy Japan Aluminium Association)

In the early stage of the Japanese industries aluminium ingots were imported and the forming and casting were the first of production. The introduction of technologies from abroad and original technologies supported the production. The smelting, on the contrary, was started late in Japan. The trial for the smelting was already started in 1897, however, it was not smoothly realized mainly because of the several difficulties such as importing bauxite, funds and cost competition. The smelting by using Japanese raw materials and technologies was started by the Showa Denko K. K. (present) in 1934. The amount was 10,000 tons/year. The raw materials used were alumstone. Then, smelting factories were constructed one after another as a national policy and became a symbolic industry. These smelting industries were, especially, for the military use including aircrafts (fighter planes). The amount of the smelted aluminium reached approximately 11,000 tons/year in 1943, just before the end of the war. This was the 4th highest in the world. The continuous process from the smelting to the product producing was established.

In 1948, the period after the war, the bauxite was imported from Indonesia to re-start smelting. In the postwar the most important issue was how to find civilian demand on aluminium. Japanese industries tried to open this difficult situation with two points, i.e., *to make steady efforts* and *to create minutely new demands*. The amount of smelted aluminium in 1961 exceeded 15,000 tons/year, higher than that in the prewar period and rapidly increased. The demand on aluminium sashes markedly

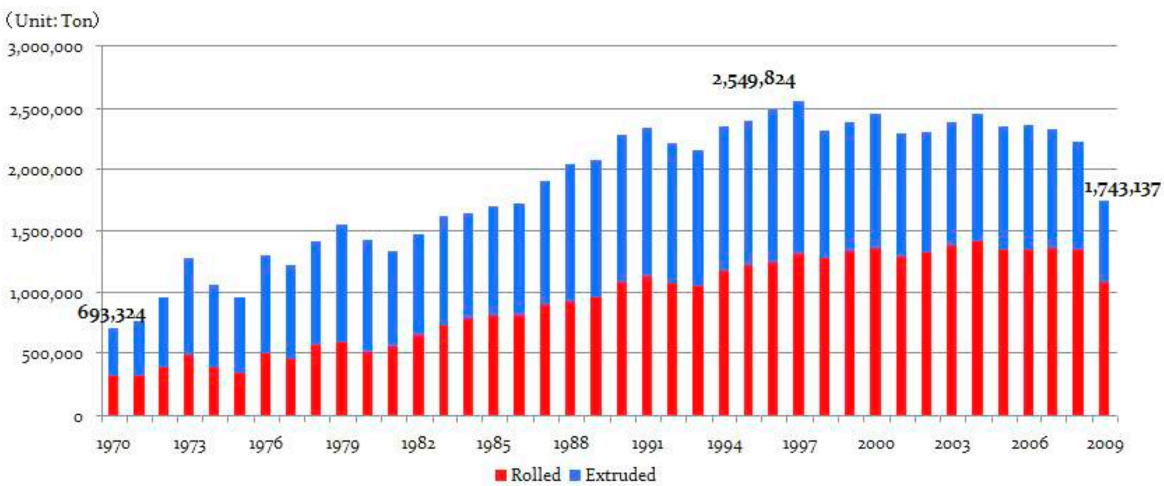

Fig.4 Trend of rolled sheets and extruded products. (courtesy Japan Aluminium Association)

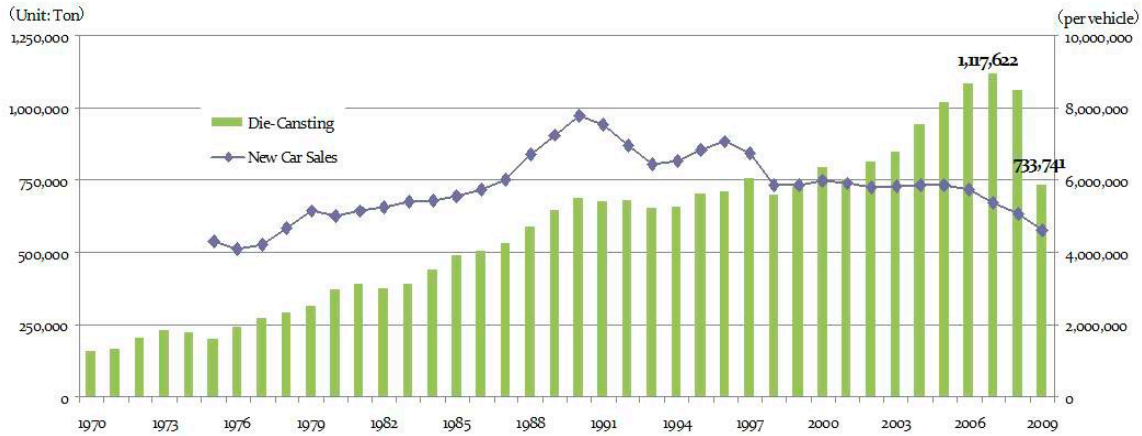

Fig.5 Trend of die-casting products together with new car sales. (courtesy Japan Aluminium Association)

Table 1 Brief history of aluminium in Japan

1867 Aluminium exhibited at the Paris World Exhibition was first introduced into Japan through Tokugawa Delegates.
1887 Al ingots were first imported to Japan.
1894 The first Al products were produced.
1898 Al sheets were produced at Sumitomo Light metal Industries (present).
1910 Al castings were produced.
1917 Al die-castings were produced.
1929 Alumite (anodized oxidation film production on Al) was first innovative technology in Japan.
1934 Al ingots were produced by Showa Denko (present).
1936 ESD (Extra Super Duralmine) was developed and produced at Sumitomo Light metal Industries (present).
1948 Al smelting was re-started.
Al industry was strongly developed.
Al sashes were dramatically developed and increased : Big Demand
1973 The first oil crisis attacked Al industries.
1979 The second oil crisis also attacked Al industries.
1986 Most of Al smelting factories were closed.
(Aluminum smelting was continued in abroad)
to Now
- New Al innovations become important.
- Secondary Al ingots(recycled Al) were used.
- Al cans have been extended.
- Al extrusions for constructions were developed.
- Al products for automobiles have been developed.
International competition becomes severe, then innovative technologies and productions are highly required.

increased after the year of 1955 and big markets for aluminium were successfully created. The aluminium sashes for the Japanese houses were attractive and comfortable, and were warmly welcomed by many Japanese. The miraculously swift growth of the economy in the postwar era took the lead of the big demand for the transportation, beverage cans and many consumer goods. The extruded products were the highest amount among the primary aluminium products. The total production ability of aluminium smelting was 1,640,000 tons/year by 14 factories of 6 companies. On the way of such favorable increase of aluminium production the situation was dramatically changed by the attack of the oil-crisis twice in 1973 and 1979. The incredibly rapid increase of the electric charge and smelting cost forced the smelting industries to lose their competitive power. The electricity greatly depended on the thermal power generator in Japan. The smelting industries, which had the total production ability of 1.6 million tons/year (the 2nd highest in the free world), were forced to be closed in 1986, just 100 years after the innovation of the Hall-Héroult process. Since then, the Japan's industrial structure was converted into the smelting abroad, i.e., all the new aluminium ingots were imported from abroad. Japan's aluminium industries met difficulties and then established a new regime with great efforts. The Japan's smelting industry experienced "*rapid growth and dramatic withdrawal*". On the other hand, the Japan's rolling plants successfully caught the public trend and succeeded to increase the demand on aluminium products. The increased demand was held up by the "*high level production technologies*" and "*incessant challenge to develop new products*". Up to now Japan stands on the processing-based national development in aluminium industry.

3.2 Innovative technologies in Japan's aluminium industry

(1) Alumite (anodizing)

Alumite is an anodic coating film formed on the surface of aluminium and its alloys by the electrolytic process. This process was first invented and developed by the research group (Dr. Syoji Sedo) at RIKEN in 1929 in Japan. The Oxalic acid was used for the electrolytic cell. Alumite is a registered trademark by RIKEN. In general, the process is now called as anodizing and widely applied to many metals and alloys. Alumite is an epoch-making invention and useful for aluminium to increase corrosion resistance and wear resistance. The surface function has been also dramatically increased by this method, and research has been carried out to extend this technology to many applications. Alumite technologies greatly contribute to increase the demand on aluminium.

(2) Development of Extra-Super Duralumin (ESD)

One of the Japanese private companies (Sumitomo Light Metal Industries, present) developed new Extra-Super Duralumin (ESD) alloys (Al-Zn-Mg-Cu based alloys) with extremely high strength [2,3]. These alloys were developed with the strong demand for aircraft structural materials and also efficient collaboration in the research group. Higher strength aluminium alloys than the Alcoa Super Duralumin (24S alloys, 45kg/mm^2) was highly requested to improve the performance of the aircraft (Zero fighters). The engineer experts on aircraft structures, engines, components and materials were called to establish the Aircraft Materials Research Group and Super Duralumin Research Group in 1935. The head of the groups was Dr. Isamu Igarashi. Dr. Igarashi focused on the combined alloys of high strength Al-Zn-Mg and Al-Cu-Mg alloys and the overcome the season cracking (or stress corrosion cracking) of the alloys. They made clear the season cracking phenomena experimentally. Dr. Igarashi's idea was superior. He kept his idea that to develop alloys without the season cracking the most important approach was to observe details of cracking in the alloys highly sensitive to the season cracking and in the next to develop alloys with no cracking. This reversed idea was efficient to overcome the difficulties. They found that the season cracking was due to the intergranular cracking of the alloys and realized the idea of the microstructure control by the combined addition of Cr and Mn to avoid cracking. The developed alloys had a standard composition of Al-8%Zn-2%Cu-1.5%Mg-0.5%Mn-0.25%Cr and the tensile strength of 58 - 60kg/mm^2 with 10 - 16% elongation. The successful development of the new alloys accelerated the rapid increase of demand on aluminium.

(3)Aluminium sashes

In Japan, aluminium sashes were first used for buildings in 1952 and for houses in the end of 1950s. The dramatic development of extrusion and surface treatment technologies accelerated the increase of the demand. The aluminium sashes for Japanese houses were attractive because of the comfortableness, durability, safety and energy saving. The technology development by the construction industry also contributed the increased number of new houses. The aluminium curtain wall was also widely applied to the outside of high-rise buildings. Concerning the production technologies, the melt treatment to reduce hydrogen gas, the DC casting technologies for the grain refinement and reduced segregation, the die designing for the improved extrusion and surface treatment technologies have been developed.

(4) Beverage cans and packaging

Nowadays, aluminium is widely used for the beverage cans and packaging of foods and medicines. Aluminium beverage cans were first developed as the DI cans by Keiser in USA in 1958. In Japan, the production was started for especially beer in 1971. The required properties for aluminium cans were ranged widely, i.e., strength, formability, thin-sheets, earing control. These requirements have been overcome through technologies. The 3004 and 3104 Al-Mn alloys with work-hardened are used for the can body materials. The technologies to control crystallized intermetallic compounds to improve formability and deformed and annealed textures have been developed. The melt treatment and DC casting processing are also very important factors. On the other hand, the 5182 Al-Mg alloy is used for the can end materials. The requirements are strength, formability and tearing properties. To achieve the requirements alloy composition and size and distribution of intermetallic compounds are carefully controlled. The production technologies for the high quality and extremely low fraction defective have been established. The subjects are to reduce the thickness of can walls for the cost reduction, the optimum design of the bottom of the body, optimized forming conditions of the neck. The requirements for the higher strength materials together with the formation technologies are also given to engineers. The bottle cans have been developed recently and the re-sealable cap is available. The improved technologies are still required for the mass production.

(5) Aluminium memory disc

Aluminium alloys are used for the memory disc materials. The examples are shown in Fig.6. The market share of Japan is very high in the world due to the high quality which meets the demand of the memory disc. The higher storage density of the memory disc is strongly requested together with the flatness and quality of the disc surface. The high strength is also required. The 5086 Al-Mg based alloy is used as the disc materials. The control of the intermetallic compounds is highly required. The points are to use high purity ingots, to reduce Al-Fe based intermetallic compounds, to suppress the growth of Mg-Si based precipitates, melt treatment, heat-treatment to release the residual stress. The gliding technology of both sides of a disc is always improved as a key issue for the high quality surfaces. To meet the demand for the higher storage density and cost reduction continuous efforts are made.

(6) Aluminium electric condenser foils

A number of electric condensers are produced and used for the electric components in the electronic circuits. The characteristic properties are required for the electric condenser, i.e., etching properties, the fraction of cubic orientation, electrostatic capacity, the influence of microalloying elements. In the industrial production, purification, melt-casting, homogenization, rolling and heat treatment technologies are extremely important. It is also necessary to identify harmful and useful trace elements and to improve surface quality of the disc.

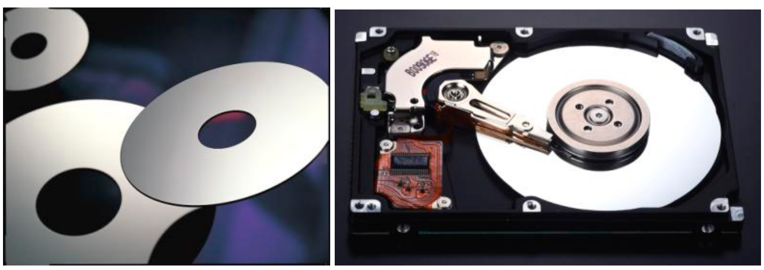

Fig.6 Aluminium memory disc and media with a head. (courtesy Toyo Kohan Co. Ltd.)

(7) Automobiles

The application of aluminium alloys to automobile bodies was for the conveyance vehicles such as a van, a refrigerator van and a wing body car. In the conveyance vehicles to deduce the weight gives the advantage for the increased payload. The clean appearance of aluminium also gives the additional advantage. On the contrary, the application of aluminium alloys for a passenger car was the components of engines. The components were mainly produced by casting and die-casting. Aluminium wheels were also produced and rapidly increased because of the fashionable appearance together with the light weight. Heat exchangers such as a radiator, an air conditioner were also made of aluminium alloys.

Fig.7 Advanced high speed Shinkansen (the Bullet Train *N700*).

Many die-castings are used for automobiles due to the superior productivity, high accuracy of dimensions and high strength. A number of researches have been carried out to produce sound die-castings. The squeeze die-casting, semi-solid die-casting, high vacuum die-casting have been developed to produce high quality automobile components. The die-cast has also an advantage that the acceptable Fe is high and useful for recycling.

On the other hand, many of the Al-Mg and Al-Mg-Si based alloys have been developed for the automobile body sheets. Especially, optimization of alloy compositions and heat treatments have been examined to improve strength, formability, corrosion resistance and bendability. Recently, the 6000 alloys are mainly investigated in Japan. The detailed investigation of heat treatments to improve bake hardening (BH) of the 6000 alloys is performed in a collaborating research work. The obtained results are used for the industrial processing. The research on the press forming has been extensively performed to optimize the conditions. The collaborating research work was carried out to increase the Rankford value (r-value) of the 6000 alloys and achieved the goal, as described later.

Recently, many aluminium alloys have been used for railway vehicles to reduce weight. In Japan, aluminium alloys were first used to a monorail in 1962. Since then, railway vehicles of aluminium alloys increase in number, including the Shinkansen (the Bullet Train). High amount of aluminium alloys are used for the most advanced Shinkansen (Fig.7). Aluminium alloys are also expected to be used for the Linear-Motor Cars, which is expected to be commercially introduced in 2025.

3.3 Research projects on aluminium alloys

Many research projects have been performed under the collaboration among universities, companies, institutes on the processing and alloy fabrications with the government support. Some of the projects related to aluminium alloys are introduced.

(1) *Aluminium-Lithium alloys and Alithium* (1989 – 1996)

The collaborating research company, Alithium, was established under the foundation of the seven aluminium companies. The collaborating research group, companies, universities and JRCM (The Japan Research and Development Center for Metals) had carried out for seven years.

Target:

(a) To establish the processing technologies of producing sound DC castings of 2090, 2091 and 8090 alloys. An induction furnace with controlled atmosphere (maximum amount of 4 tons).
(b) To produce sheets and plates of 2090, 2091 and 8090 alloys.
(c) To evaluate microstructures and properties such as strength, elongation, toughness, fatigue.
(d) Al-Li alloy development: new alloys, superplasticity.

Results: The fabrication technologies of DC castings were well established. Sheets and plates with superior properties were successfully produced. Many experimental data were obtained and valuable Data-base was created. The fundamental understanding of Al-Li alloys was sufficiently obtained. The project was closed in 1996. The sufficient demand was not found unfortunately mainly because of the cost.

(2) *Development of Super-aluminium with high strength and high corrosion resistance* (1997 – 2002)
Research Group: NEDO (New Energy and Industrial Technology Development Organization), JRCM, aluminium companies, universities

Target:

(a) To produce ultra fine grains, smaller than 3μm.
(b) To obtain 1.5 times higher strength and corrosion resistance.

Results: Ultra fine grains were produced by the process controlling without any additional uncommon elements. High strain was accumulated by the deformation at liquid nitrogen temperature. The combination of warm-rolling and annealing was effective to produce fine grains. The asymmetric warm-rolling to introduce shear strain was also useful. The target of the project to produce ultra fine grains, smaller than 3μm with 1.5 times higher strength was successfully achieved.

(3) *Nano-technology and Nano-aluminium alloys* (2001 – 2006)
Research Group: NEDO, JRCM, universities, aluminium companies

Target:

(a) To control nanoclusters and nano-precipitates.
(b) To control grain boundary structures.
(c) To create simulation methods for the nanocluster formation.

Results:

The 6000 series alloys for automobile body sheets: nanoclusters and nano-precipitates were well controlled based on the detailed understanding of the phenomena. Both the strength with the BH treatment and elongation were achieved. The 3-dimmensional atom probe (3DAP) images of nanoclusters and nano-precipitates (the β” phase) are shown in Fig.8 [4].

The PFZ (Precipitates Free Zone) was well controlled in Al-Zn-Mg and Al-Mg-Si alloys by the microalloying elements and heat treatments. Both the strength and elongation were increased by the PFZ control.

The atom-atom interactions and atom-vacancy interactions were calculated by the First Principal method. By using these interactions the formation behavior of nanoclusters with containing microalloying elements were successfully simulated. The simulation method was established.

(4) *High formability and high performance aluminium alloys for light weight automobile applications* (2002 – 2007)
Research Group: NEDO, JRCM, aluminium companies, universities

Target:

(a) To develop high formability aluminium alloy sheets for automobiles.
(b) To develop Aluminium/Steel hybrid structures.
(c) To develop highly reliable porous aluminium alloys.

Results:

The r-value 0.6 of the conventional aluminium alloys was increased to 1.2, almost the same as that of steel. The texture was

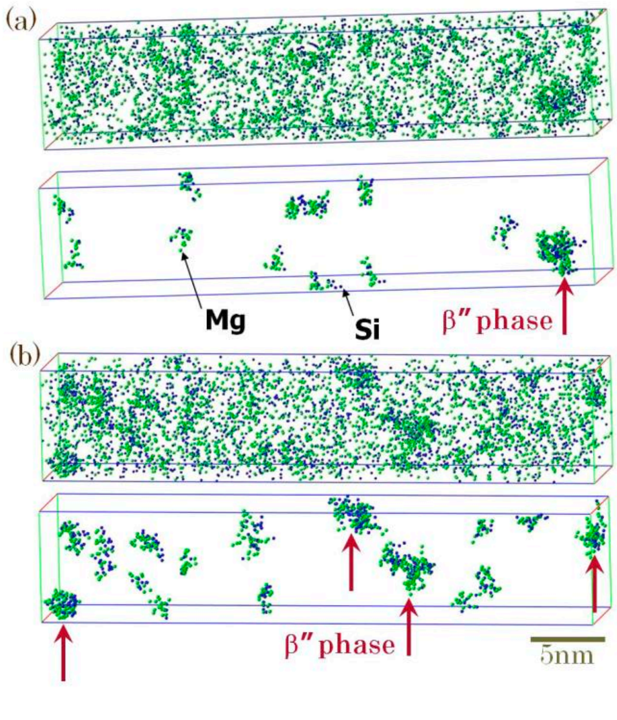

Fig.8 3DAP (3-dimensional atom probe) images of nanoclusters and nano-precipitates in the aged Al-Mg-Si alloy . Dots shows atoms.[4] (a) Cluster (1) and (b) Cluster (2).

controlled by the asymmetric rolling and annealing of the 6000 alloys. The strength of the joint of Al alloy/steel was achieved to be similar or higher than that of the rivet. The reliability was also achieved. The porous aluminium alloys for the crush energy absorbing equipments of automobiles were produced by several methods. The fabrication process of the reliable light weight porous aluminium alloys was established. These results are well applied to contribute the light weight automobiles.

Many other collaborating research works have been carried out by the support of Japan Aluminum Association (JAA), Light Metals Foundation together with Japan Institute of Light Metals (JILM).

4. Aluminium technologies and industries in future

Road-maps are established for the future aluminium under cooperation between Japan Institute of Light Metals (JILM) and Japan Aluminium Association (JAA). The user companies such as automobiles, transportations, constructions are collaborated to establish the road-maps. The road-maps are for the fundamental researches and for the processing and product technologies. The concept to decrease the cost by alloy designing with low cost elements, innovative production technologies and highly efficient recycling is included. To find new demands on aluminium in the automobile, transportation, construction industries is also targeted. An innovative way is to be found for future by putting heads together, “Out of counsel of three comes wisdom”.

5. Summary

The brief history of aluminium industries and several innovative technologies are introduced. Since the aluminium industry was started in Japan great efforts have been made to improve quality and to reduce cost of products. Although the oil-crisis forced to withdraw the smelting industry many innovative technologies have made it possible to increase the demand on aluminium. Collaborating research projects are extremely important and effective to create innovative technologies and to open new demands on aluminium. The road-maps suggest us the next challenges for aluminium in Japan.

References

[1] Aluminium Handbook, Japan Aluminium Association.
[2] K. Nagata: J. Japan Institute of Light Metals, 60(2010), 192-201.
[3] M. Ogawa: *Aluminum*, Nikkei Inc., (1990)
[4] T. Sato: J. Japan Institute of Light Metals, 56(2006), 592-601.