Advanced Performance Materials 5, 291–306 (1998)

The Status of the Aluminum Sheet and Plate Industries and Related Research Activities in Korea

SUK-BONG KANG
Materials Engineering Department, Korea Institute of Machinery and Materials, Changwon, Kyungnam 641-010, Korea

Abstract. This paper was prepared to review the status of the aluminum sheet and plate industries and related research activities in Korea. The aluminum sheets and plates which have been produced in Korea are mainly non-heat treatable alloys, so that the installations of the heat treatment facilities for producing the heat treatable sheets and plates are considered recently by aluminum industries in Korea. Concerning the research activities on the aluminum sheets and plates in Korea, the research topics and contents are mainly described on the basis of the highly advanced national projects which have been started since the middle of 1992.

Keywords: aluminum sheet and plate industries, research activities, highly advanced national projects, high strength aluminum alloys, weight saving, transportation system

1. History of the aluminum sheet and plate industries in Korea [1]

Two types of manufacturing processes have been employed to produce the aluminum sheets and plates; one is continuous casting and the other is hot and cold rolling of the slabs. The products of the former process are usually called as the continuous cast sheets and plates, and the ones of the latter process as the common sheets and plates. In Korea, Choil Aluminum Mfg. Co. Ltd. (hereinafter referred to as 'Choil') had initially started to produce the common sheets and plates (600 mm width) by installing direct chill caster, and hot and cold rolling lines in 1975. The company had later installed the 3C jumbo caster to produce the continuous cast sheets and plates (1,350 mm width) in 1979. Meanwhile, Dongsung Aluminum Mfg. Co. Ltd. (hereinafter referred to as 'Dongsung'), which was initially called as Hyosung Aluminum Co., had also started to produce the continuous cast sheets and plates since 1980. Therefore, up to the year of 1992, the continuous casting sheets and plates had mainly been produced by the two companies in Korea. Choil and Dongsung had supplied the continuous casting sheets and plates equivalent to the annual production capacity of 70,000 to 80,000 tons. The production of aluminum foils amounted to 80% of the total demands. Excluding the usage for aluminum foils, the continuous casting sheets and plates have partly been used for the applications without surface treatments, for instance, aluminum pre-sensitized sheets or fin materials.

The high strength and high formability aluminum sheets and plates, such as surface treated products, aluminum cans, aluminum pre-sensitized sheets and clad materials for heat exchanger could not be manufactured by the continuous casting processes. Therefore, nearly all of these demands were solved by the imports from overseas which amounts to about 100,000 tons annually, even though small amounts were domestically supplied by the old-fashioned facilities only producing narrow width products. Choil was the only corporate having hot and cold rolling facilities for narrow width slabs, which was installed 20 years ago and has the annual production capacity of about 7,000 tons at the most. Since Aluminum of Korea Ltd. (hereinafter referred to as the 'Koralu') started aluminum smelting from 1969 for the first time in Korea, it has transformed to a new aluminum hot and cold rolling mill company from 1993. Nearly at the same period, Taihan Electric Wire Co. Ltd., Youngju Plant (hereinafter referred to as the 'TEC Youngju') has operated a new aluminum hot and cold rolling mill. Those two corporates installed casting shop, hot and cold rolling shop, product shop and related ancillary facilities. Each company can produce 100,000 tons of aluminum products annually. Koralu technically joined hands with Nippon Light Metal of Japan, while TEC Youngju cooperated with Kaiser of U.S.A. through a technical assistant agreement. At present, two companies of Choil and Dongsung can produce the continuous casting sheets and plates, while four companies of Koralu, TEC Youngju, Choil and Seoul Light Metal Co. can produce the common sheets and plates. Choil has started installing new continuous casters to increase its production capacity of continuous casting processes from 70,000 tons to 140,000 tons, which will be operated from early 1997. While Koralu and TEC Youngju also planned to start the extension of installations to produce heat treatable sheets and plates, it is estimated that the extension schedule to be postponed due to the burden of excessive investment and a vague market environment.

2. The current status of the aluminum sheet and plate industries in Korea

2.1. Production processes and related facilities [2–4]

The manufacturing processes to obtain the aluminum sheets and plates are schematically described in figure 1. Each process and related facilities are briefly reviewed on the basis of the factories under the operation in Korea. Raw materials, ingot and master alloys are charged, melted and stirred in melting furnace. The melting furnaces are equipped with electromagnetic stirrer to reduce the melting time and metal loss, and recuperator to reuse the thermal energy of exhaust flue gases. The molten metal is analyzed and corrected to the required chemical compositions, cleaned and settled in holding furnaces. The hydrogen gas and nonmetallic inclusions in molten metal are removed through in-line degassing (Alpus) and filtering equipment during transfer of the moltens from holding furnaces to casting machines. The maximum casting capacity reaches up to 30 tons for $600^{t} \times 2,200^{w} \times 8000^{l}$ slab. The side and edge of cast slab are scalped to remove inverse segregation layers or oxides. For homogenizing the structure, scalped slabs are heated at soaking pit furnace. Thick cast slabs are rolled down to plates and thin strip hot coils to 2 mm by repeated rolling above recrystallization temperature range of 440°C to 610°C.

The rolling ratio of each rolling pass is automatically controlled with computerized input by adopting automatic gauge control and automatic crown control system. In order to minimize the thickness tolerance, the Feedback mode (GEFC) is installed for fine control of the roll gap by compensating the thickness deviation of plate at outlet side. Roll eccentricity compensation (REC) is also equipped to optimize the shape of plate. Hot coils are re-rolled through cold rolling and annealing to final gauges, ranging from 6 mm to 0.08 mm to match customers' various requirements in physical properties, such as tensile strength, elongation

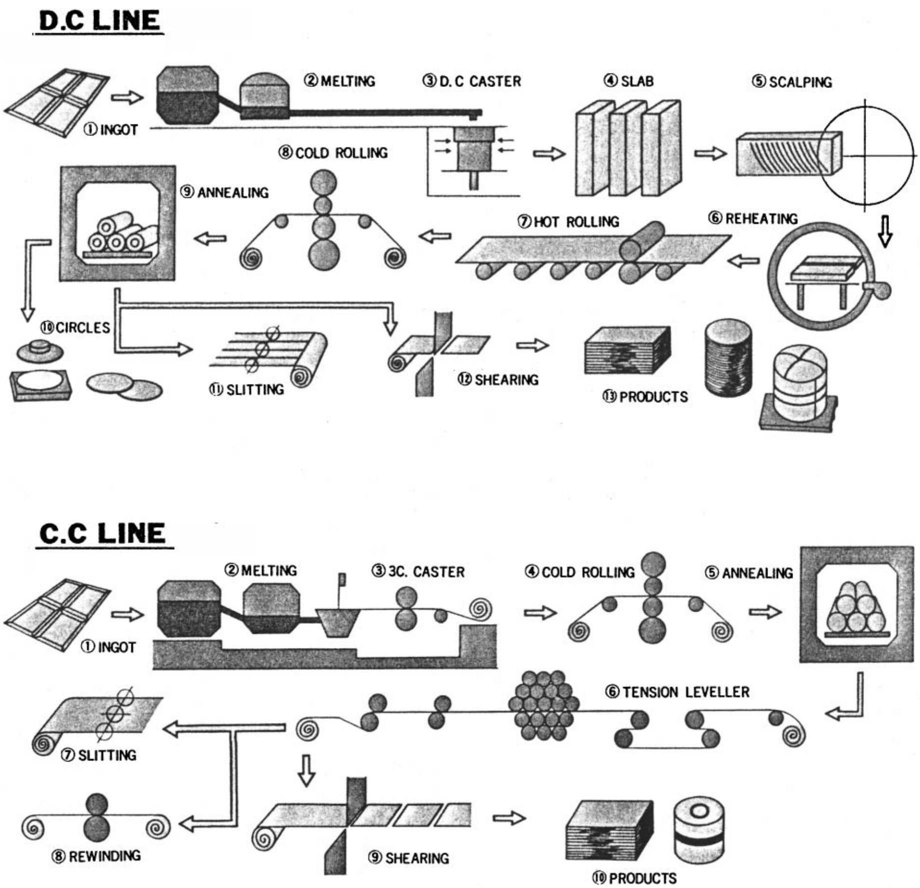

Figure 1. Manufacturing processes to obtain the aluminum sheets and plates.

and drawabilities. For producing high quality cold rolled products, the cold rolling mill is also installed with controlling equipment such as automatic gauge control (AGC), automatic flatness control (AFC), roll eccentricity compensation (REC) and variable crown roll. The main difference of facilities installed in those two rolling mills employing companies is that Koralu is equipped with 4 high reversing single stand hot mill and 4 high nonreversing cold mill, while TEC, Youngju Plant is equipped with 3 stand tandem hot rolling mill and 2 stand tandem cold rolling mill including single stand hot and cold rolling mill.

The annealing furnaces are used to remove the residual stress formed during cold rolling. Inert gas is supplied to the furnace for preventing the sheets from oil stain due to coolant of cold rolling mill. For finishing process from cold coils to various coils and sheets, to meet the needs of customers, there are several tension leveling, slitting, shearing and surface treatment equipment. And for all canstocks there are also continuous strip cleaning and D.O.S. oil coating line and scroll shear.

2.2. Production capacity and demand

Because the applications of the continuous casting sheets and plates are limited to tube materials or fin materials, the most of sheets and plates are produced by the manufacturing processes of the hot and cold rolling the slabs. Continuous casting process has an advantage of lower installation cost, but it is a great disadvantage for continuous casting process that the alumite treatment cannot be adopted. The status of supply and demand for aluminum sheets and plates up to the year of 1992 is shown in figure 2 [1]. Since 1993, Koralu and TEC Youngju have started to produce and supply the common sheets and plates in domestic market. The main facilities and production capacity of domestic aluminum sheets and plates manufacturing companies are described in Table 1. Table 2 shows the status of market share among the domestic major aluminum sheets and plates manufacturing companies in 1995 [2–4]. As shown in Table 2, the domestic demands for aluminum sheets and plates amount to 250,000 tons, half of them are supplied by the domestic production and the remainders are supplied by the import. Koralu and TEC Youngju have made their efforts for the import substitution. At present, the production capacity of the hot and cold rolling facilities surpassed the domestic demands. The surplus supply should be solved in a short period, but it is estimated that the difficulties can be surmounted by import substitution and new market development for export and domestic supplies.

The producible alloys are 1100, 1050, 1235, 3003, 3004, 5052, 5182 including 2020, 6061 and 7XXX series alloys. These alloys are used for cans, foil, p.p. cap, heat exchanger fin, architectural materials, utensil raw materials, clad materials, electric-electronic materials, structural materials, name plates, defense-industry material, etc. The application and characteristics are demonstrated in Table 3. The dimensions of various producible commodities are shown in Table 4 [2–4].

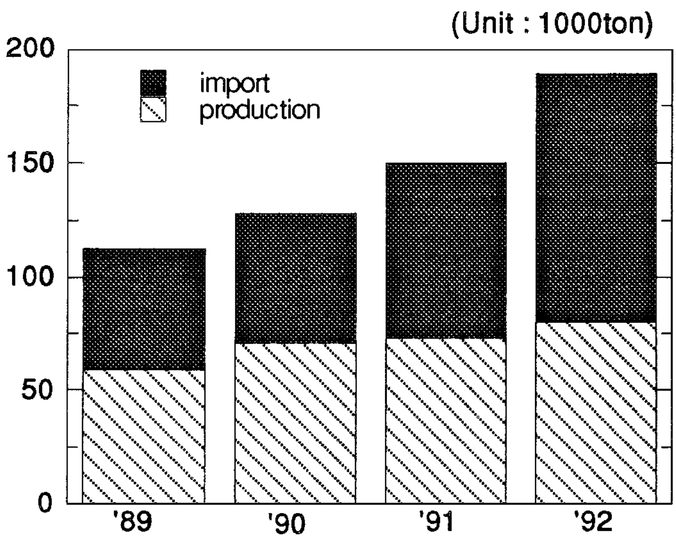

Figure 2. Status of supply and demand for aluminum sheets and plates up to the year of 1992.

Table 1. The main facilities and production capacity of domestic aluminum sheets and plate manufacturing companies.

Companies	Main facilities	Annual production capacity
Continuous casting sheets and plates		
Choil Aluminum Co.	Continuous Caster (width 1750 m/m) × 5 unit 4 high Cold Rolling M/C × 3 unit	80,000 tons
Hyosung Aluminum Co.	Continuous Caster (width 1600 m/m) × 1 unit Continuous Caster (width 1500 m/m) × 2 unit Continuous Caster (width 1200 m/m) × 1 unit	36,000 tons
Common sheets and plates		
Aluminum of Korea Ltd.	4 high reversible Hot Rolling M/C × 1 unit	Hot Rolling 150,000 tons
	4 high Cold Rolling M/C (2250 m/m) × 2 unit	Cold Rolling 120,000 tons
Taihan Electric Wire Ltd. Co., Youngju Plant	Reversible Hot Rolling M/C × 1 unit	Hot Rolling 300,000 tons
	3 stand Tandem Finishing Hot Rolling M/C × 1 unit	Cold Rolling 120,000 tons
	2 stand Tandem Cold Rolling M/C × 1 unit Cold Rolling M/C × 1 unit	
Choil Aluminum Co.	Hot Rolling M/C (width 600 m/m) × 1 unit Cold Rolling M/C× 1 unit	10,000 tons

Table 2. Status of sales of aluminum plate and sheet in 1995 (unit: ton).

	Domestic market	Export	Subtotal
TEC, Youngju	26200	11,200	37,400
Koralu	21,000	24,500	45,500
Dongsung	21,000	6,600	27,600
Choil	39,600	130	39,730
Total	107,800	42,430	150,230

3. The R&D activities on the aluminum sheets and plates in Korea [5]

Recently, the transportation industries required high strength aluminum alloys for replacing the steel components in the transportation systems. Since 1992, the collaborative research projects, called as highly advanced national projects (HAN projects), among national research institutes, industries and universities have been initiated. The main objective of this research is to develop new high strength aluminum alloys for weight-saving of the transportation systems. This research project related on developing high strength aluminum alloys consists of four parts of subprojects. These are (1) research on high strength and

Table 3. The application and characteristics of producible aluminum alloys.

Series	Alloy	Application	Characterization
1000	1235	Foil stock	Good formability, corrosion resistance, weldability electrical and thermal conductivity
	1050	Fin stock, cosmetic cap, utensils, name plate, litho sheet, architectural panel, evaporator	Usage for decorator, reflector, printing plates, home utensil due to good reflecticity, corrosion resistance and electrical conductivity
	1145	Foil stock	
	1100	Fin stock, solar collector, condenser case	
3000	3003	Architectural materials Utensils Fin stock	Increase strength without degrading formability and corrosion resistance, which is equivalent to 1000 series alloys
	3004	Can body	
	3105	P.P. Cap	
4000	4343	Welding wire	Usage for braging materials and brazing sheet due to lower melting point
	4043	Radiator fin Clad	
5000	5005	Automotive parts Architectural parts	Having the highest strength among non-heat treatable aluminum alloys, especially good compatibility to environment
	5052	Container, van truck Automotive parts	
	5082	Can end	
	5182	Can tab, can end	
	5083	Can end Marine parts Defence parts Transportation equipments	
8000	8011	P.P. Cap	Having superior formability suitable for p.p. cap

Table 4. The dimensions of various products.

	Thickness (m/m)	Width or dia. (m/m)	Weight (ton)
Coil	0.08–3.0	max. 2,100	28
Sheet	0.08–6.0	max. 2,100	—
Plate	max. 150	max. 2,500	—
Circle	0.5–5.0	max. 900	—

high formability aluminum alloy sheets, (2) research on weldable high strength aluminum alloys, (3) research on low density high strength aluminum-lithium alloy and (4) research on development of superplastic alloys and superplastic forming technology. Each subprojects have their specific research objectives. High strength and high formability aluminum alloy sheet materials are intended to use for automobile, weldable high strength aluminum alloys are for defense and railway industry usage, Al-Li alloys are for airplane, and superplastic aluminum alloys are for airplane and automobile application. To efficiently utilize the results of this research, collaboration with the related industries is definitely needed. Scopes and results of each research project are described briefly as follows.

3.1. High strength and high formability aluminum alloy sheets for automobile body panel applications

The weight reduction of automobile is indispensable for fuel saving and higher performance because the fuel consumption increases proportionally with the weight of automobile. Recently, automobile makers all over the world have prudently considered the weight reduction for improving fuel economy since a bill of Cooperate Average Fuel Economy (CAFE) was passed in America for the worldwide environmental protection [6]. Under these circumstances, aluminum alloy sheets for autobody panels are supposed to be the most promising materials for reducing the weight of the car. In America, cars with hood, door and trunk lid made of aluminum alloys have been produced for practical use since 1970, as a result of active researches on this field. In order to replace steel sheets with aluminum sheets for autobody panels, the development of high-formability and high-strength aluminum alloys are required.

This project has been carried out to develop the high-formability and high-strength aluminum alloys which can substitute low carbon steel sheets with aluminum sheets for autobody panels. The developed aluminum alloys should have better properties such as strength, formability, corrosion resistance, weldability and surface treatability than low carbon steel sheets. Therefore, the scope of this project is intended to deal with the related technologies such as welding, forming, surface treatment and painting for the purpose of utilizing most of the existing facilities in the present automobile production lines.

In order to develop the high-strength and high-formability Al-Mg alloy and Al-Mg-Si alloys sheets, this research work has been carried out to obtain the basic information of melting and solidification technologies, hot deformation, texture of rolling, characteristics of heat treatment, mechanical properties and its theoretical background, precipitates analysis, X-ray diffraction peak analysis and so on [7–11]. Based on the abovementioned basic information, manufacturing processes for mass production were set up to develop the domestic aluminum alloys having strength of 300 MPa and elongation of 30%. Based on laboratory experiment, the related research team tried a mass production of sheets of modified AA5182 aluminum alloy by using the production facilities at Koralu. In addition, they also studied the related autobody manufacturing technologies such as weldability, formability, surface treatability and paintability. A study on the multilayer spot welding was carried out to evaluate the characteristics compared to the two-layer spot welding. Characteristics of STAR electrode for spot welding developed by Sumitomo Light Metal Ltd. was also examined. As for a study on the surface treatability and paintability, experiments for improving the characteristics of phosphating solution, surface treatability of domestic aluminum alloy sheets, one-step process for two different metals, performance of painted specimen and so on were carried out to obtain the optimum conditions for surface treatment. Meanwhile, a prototype of the aluminum autobody structure was manufactured with the imported aluminum alloy sheet as a study for formability, and was also evaluated for the applicability

Figure 3. External appearance of automobile attached aluminum panel.

of the aluminum alloy sheets as autobody panels through performance tests of attachment, strength, stiffness and wear-resistance (see figure 3) [12].

In the second stage research period of August 1995 to July 1998, the domestic aluminum alloys having strength of 350 MPa and elongation of 35% will be produced by using mass-production facilities on the basis of the research results obtained in the first stage research period. Additionally, we are also planning to investigate the related autobody manufacturing technologies such as weldability, formability, surface treatability and paintability on the domestic aluminum alloy sheets, so that we can determine the applicability of the domestic aluminum alloy sheets as autobody panel. Finally, we will manufacture a prototype of all aluminum structured vehicle with domestic aluminum materials.

Regarding the new alloy development, the target of this research is to develop the alloys having enhanced formability and no stretcher strain mark in 5XXX series aluminum alloys. While, for 6XXX series aluminum alloys, the target is to develop the alloys having improved bake hardening properties. As one of the research results of 5XXX series aluminum alloys, tensile properties of 300 MPa tensile strength, 150 MPa yield strength and 35% elongation could be obtained from the alloys of Al-(7–8 wt.%)Mg-Cu, Al-(7–8 wt.%)Mg-Zn, Al-(7–8 wt.%)Mg-Zr, Al-(7–8 wt.%)Mg-Si, and Al-(7–8 wt.%)Mg-Zn-Cu. Figure 4 shows the tensile properties of typical two alloys among them [13].

Hardness measurement and tensile test were performed to study the effects of natural aging and pre-aging on the subsequent precipitation process and mechanical properties of an Al-0.95Mg-1.55Si-0.1Zr alloy (wt.%) [14, 15]. Figure 5 shows the influence of natural aging on the hardness of specimens aged at 180°C. The results show that the peak hardness decreases continuously with the increase in natural aging time before artificial aging, giving direct evidence of the deleterious effect of natural aging. The increase in natural aging time results in the decrease in the concentration of both solute atoms and vacancies, due to

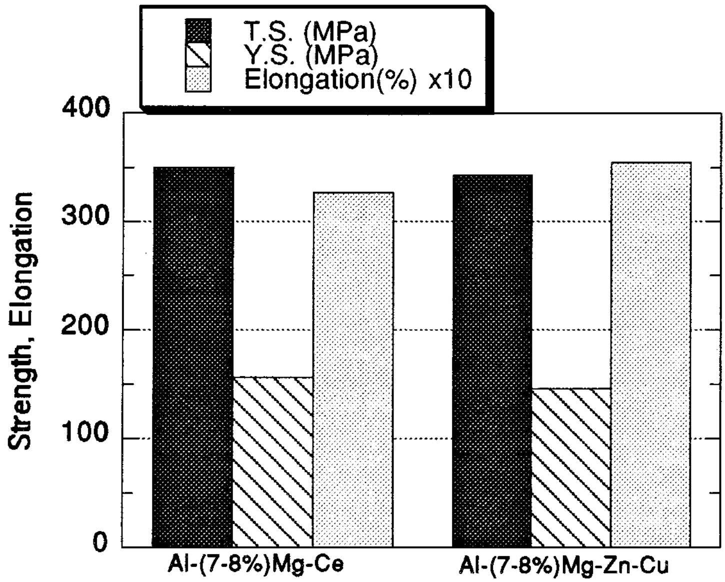

Figure 4. Tensile properties of new Al-Mg alloys.

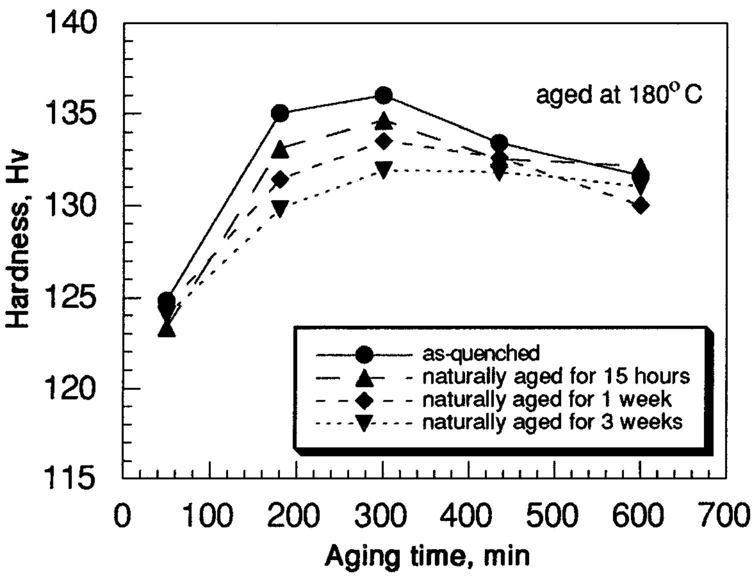

Figure 5. Change of hardness upon aging at 180°C for specimens naturally aged for different times.

the formation of more clusters which consume both solutes and vacancies. Therefore, the precipitation behavior during subsequent artificial aging is affected, leading to the decrease in hardness with increasing natural aging time.

In order to imitate the paint baking process for a car body sheet, an aging treatment of 180°C/30 min were performed for specimens naturally aged for 3 months and for those pre-aged at 150°C for 5 min immediately after water quenching and then naturally aged for 3 months. Comparisons of tensile properties for specimens before and after 180°C/30 min aging treatment are shown in figure 6. For specimens without pre-aging, the increment of tensile and yield strength caused by the 180°C/30 min aging are 27.7 and 52.2 MPa, respectively, while those for pre-aged specimens are 48.2 and 84.4 MPa, respectively. The results indicate that pre-aging at 150°C for 5 min can suppress the detrimental effect of natural aging. The tensile results show that pre-aging at 150°C for 5 min immediately after quenching can suppress the formation of clusters effectively. The reason that pre-aging can suppress the clustering process is based on the suggestion that nuclei of β'' can be formed during pre-aging process. The formation of β'' nuclei leads to the reduction of both solute content and vacancy concentration in solid solution, resulting in the suppression of clustering during the natural aging process.

3.2. Weldable high strength aluminum alloys

In general, high strength aluminum alloys have been widely used especially for aircraft and military applications because of their high strength to weight ratio. Particularly, many studies have been conducted to weldable high strength aluminum alloys for military applications in advanced countries, and on the basis of the results of these investigations, those alloys such as Al 7039, Al 7017 and Al 7020 were developed. However, there have been no reports on these investigations in Korea. Considering many applications of the weldable high strength aluminum alloy in some industries such as defense, automobile and high speed train, the demand for the weldable high strength Al alloy will be substantially increased in the near future, therefore, this research needs to be urgently conducted in this country.

New weldable high strength aluminum alloy was developed in laboratory scale and as a result patents were granted. Therefore, the purpose of this research is to develop the optimum processing conditions in melting, casting, and thermomechanical treatment for practical use of the new weldable high strength aluminum alloy. In order to investigate the optimum conditions in melting and casting which are the basic techniques for production of new weldable high strength aluminum alloy, pilot plant scale products were used in this study. Using the technical data obtained from the laboratory research, pilot plant scale experiment has been performed by semi-continuous casting method and the optimum conditions have been obtained in this study. The behavior of Mn containing dispersoid has being carried out since it significantly influences the mechanical properties. In 7XXX series aluminum alloys it was observed that the size and morphology of Mn containing dispersoid were influenced by casting temperature, homogenizing temperature, heating rate in homogenization and rolling processes. In developing hot rolling technique produced by the semi-pilot plant scale, the optimum parameters were established for hot rolling. In the development of thermomechanical treatment technique, by changing the aging conditions

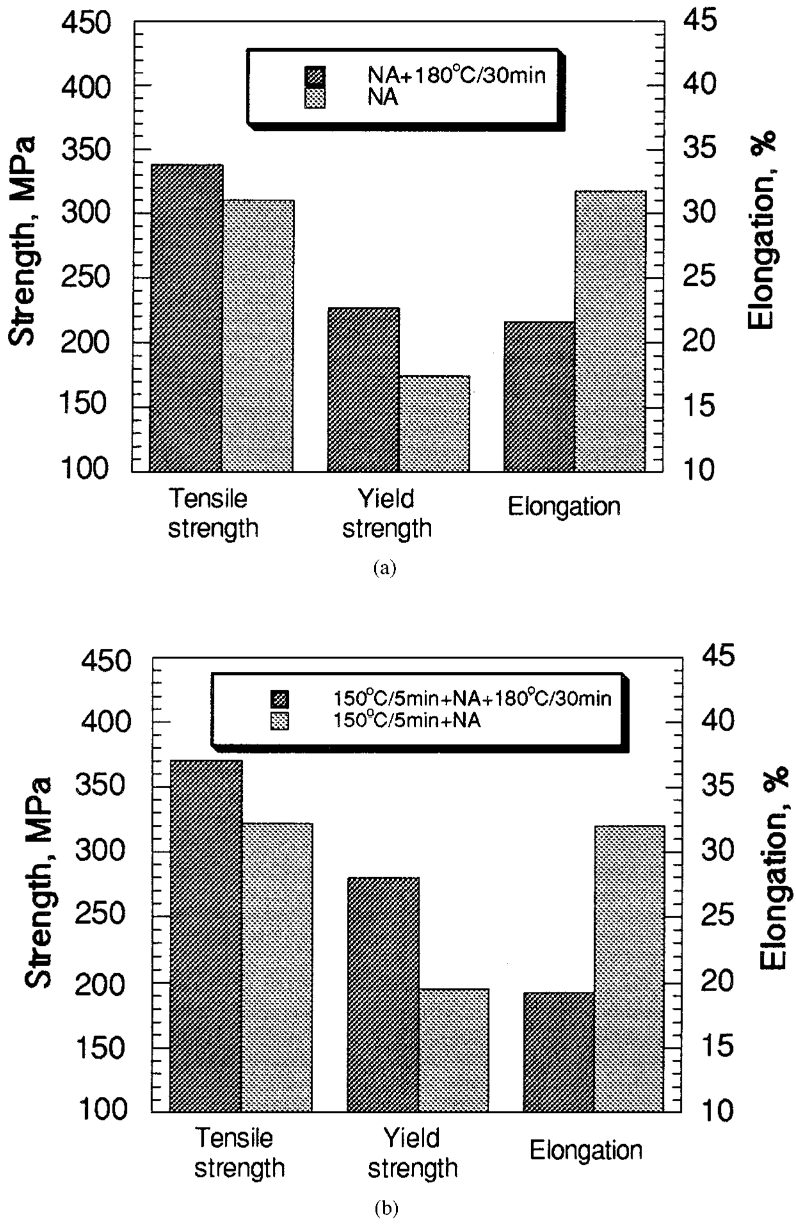

Figure 6. Comparisons of tensile properties for specimens before and after 180°C/30 min aging treatment: (a) without pre-aging; (b) pre-aged at 150°C for 3 min.

after thermomechanical treatment, YS and UTS were increased more than 20%. These techniques are new and superior to those reported previously. To increase the strength of welded part in the structural Al alloy, this study was also devoted to develop the high strength welding wire which has the much higher strength than the commercial welding wire. The weldability of the alloy is evaluated by analyzing the GMAT and GTAW welding results. Production line of the new alloy in commercial scale is now under consideration for construction.

3.3. Low density high strength Al-Li alloy [5]

Aluminum-Lithium alloys are useful as weight saving materials for the future transportation systems. The new alloy development and its applications have been studied intensively in the well developed countries since 1970. Even though there were limited research activities on Al-Li alloy in Korea, the first systematic research on Al-Li alloys was started in 1988. New alloy development and study on manufacturing methods are the two major topics of this research. Open air melting process was developed and patented through this systematic research in 1990. In the laboratory scale experiment, the capacity of the melting process was about 25 kg and the size of a casting billet was 20 kg weight and 7 inches in diameter. Research on the new Al-Li alloys were started in 1991. Al-Li-high Cu-low Mg alloys and Al-Li-high Mg-low Cu alloys were studied during 1991–1995. The effects of small addition of Mn, Ag, Ce, and La were analyzed, and some promising results were found. The alloy compositions and mechanical properties are shown in Tables 5 and 6. New alloys showing yield strength of 437 MPa, elongation of 8.7% and specific gravity of 2.54 g/cm^3 have been developed.

Table 5. Chemical composition of Al-Li-high Mg-Cu-Mn alloy.

Alloy no.	Li	Mg	Cu	Mn	Zr	Fe	Si
1	2.10	3.09	0.93	0.01	0.11	0.08	0.01
2	2.13	3.17	0.96	0.28	0.16	0.07	0.03
3	2.04	2.01	0.83	0.49	0.14	0.07	0.02
4	2.11	3.18	0.90	0.65	0.13	0.05	0.02
5	1.93	3.14	0.89	0.48	0.01	0.08	0.03

Table 6. Tensile properties of Al-Li-high Mg-Cu-Mn alloys.

Alloy no.	YS (MPa)		UTS (MPa)		Elongation (%)	
	L.D.	T.D.	L.D.	T.D.	L.D.	T.D.
1	402	385	527	506	8.8	7.3
2	444	405	551	552	7.6	8.5
3	437	421	553	537	8.7	5.4
4	441	424	542	527	5.0	4.8
5	384	389	489	402	6.9	4.0

Concerning the development of new alloys, various kinds of Al-Li alloys were prepared by adding Mn. The effect of Mn addition on the corrosion, low cycle fatigue, and fracture toughness were also studied. The addition of Mn to Al-Li alloy was found to be effective for improving corrosion resistance. Corrosion potential was increased as shown in figure 7. Cyclic plastic strain energy was changed in various Mn containing Al-Li alloys. Maximum strain energy was obtained in 0.3% Mn containing alloy as shown in figure 8.

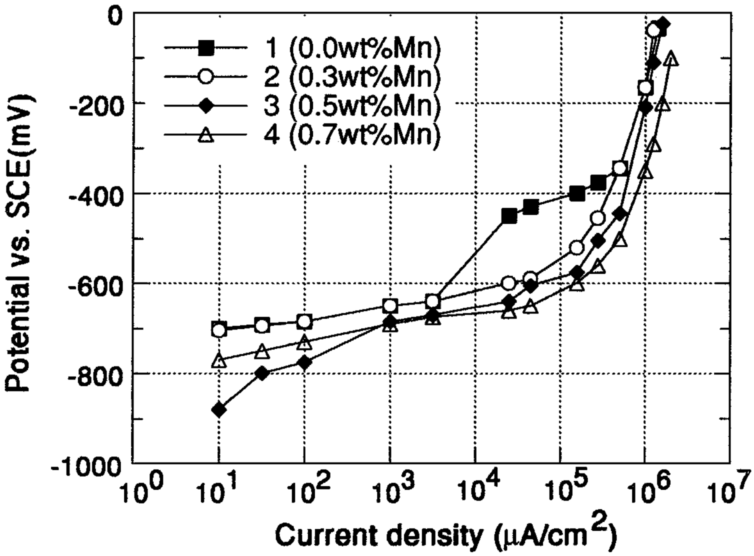

Figure 7. Anodic polarization curves of Al-Li-high Mg-Cu-Mn alloys at various Mn contents.

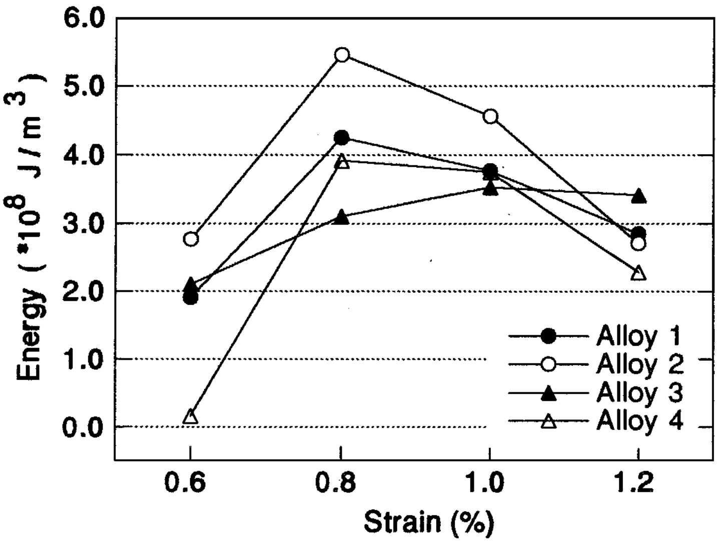

Figure 8. Cyclic plastic strain energy to failure for Al-Li-high Mg-Cu-Mn alloys in low cycle fatigue.

During this new alloy development, processing difficulties associated with impurity control in open air melting process were encountered. In order to solve these difficulties, research on protective melting in a medium scale production was required. Therefore, Russian technology for producing Al-Li alloy was obtained from VILS in Russia. The possibility of combining the technology of the open-air melting process with Russian vacuum melting process is studied. Research on the production technology of Al-Li alloy in pilot scale has been carried out by using the Russian technology.

3.4. Superplastic aluminum alloys and superplastic forming technology

In the foreign countries, many research works have been performed to develop the superplastic alloys such as Al-Li [16, 17], 7075, 7475 [18], 5XXX [19, 20], Cu-Al, duplex stainless steel and Ti alloys. On the other hand, many research works have also been performed to develop the superplastic forming technology such as sheet blow forming process [21, 22], analytical solution [22, 23] and finite element simulation [24] for blow sheet forming and bulk press forming processes. In Korea, two kinds of new superplastic aluminum alloys and special manufacturing method have been developed, which are now patent-pending. The mechanical properties of superplastic aluminum alloys are described in Table 7. As shown in Table 7, KIST 5000 alloy and KIST 2000 alloy which are based on conventional 5XXX aluminum alloys and Lockheed invented alloy (Al-3Cu-2Li-1Mg-0.15Zr) respectively, show excellent superplasticity (large elongation at high strain rates) and low cavitation. The costs for materials and manufacturing are expected to be low in these new alloys. The related research teams are planning to continue their research works to develop new superplastic alloys based on 2XXX and 6XXX series alloys and superplastic forming technology.

Table 7. Mechanical properties of superplastic aluminum alloys.

Major alloying element	Alloys	Temperature (°C)	Strain rate (s^{-1})	Maximum elongation (%)	Strain rate sensitivity (m)	Room temperature tensile strength (MPa)	References
Cu, Zr	Supral 100	450	2×10^{-3}	1200	0.5	430	[25, 26]
	Supral 220	480	3×10^{-3}	1100	0.5	490	[27]
Mg	KIST 5000	530	10^{-3}	700	0.5	340	[20]
	Supral 500	500	10^{-3}	230	0.35	220	[28]
	SP 5083	450	2×10^{-4}	460	0.6	300	[29, 30]
	Neopral	550	10^{-3}	700	0.7	330	[25, 26, 31]
Zn, Mg	KIST 7475	535	2×10^{-3}	1500	0.7	575	[18]
	SP 7475	515	2×10^{-4}	1000	0.7	575	[32]
Li, Cu	Lital 8090	530	10^{-3}	900	0.45	490	[18]
Cu, Li	KIST 2000	530	2×10^{-2}	1200	0.55	650	[16]
	SP 2090	520	10^{-3}	1200	0.55	600	[32]

3.5. Other aluminum alloys

The aluminum sheets and plates manufacturing industries have been focusing their research activities on producing the alloys to replace the imported alloys. For instance, R&D activities on canstocks, clad materials for heat exchangers, litho sheets, foils for electrolytic condenser are now on the way to meet domestic demands. It is estimated that their R&D activities will be expanded to cover the foreign and future domestic market.

4. Concluding remarks

The aluminum sheets and plates manufacturing industries in Korea have strived to produce high quality products that meet the highest degree of world quality standards by their excellent quality control capabilities and technical services. It is fundamentally essential for the aluminum industries to strengthen ties with aluminum consumers to accurately grasp their needs and to pursue efficient research and development endeavors to meet those needs.

The aluminum sheets and plates which are mainly produced in Korea are non-heat treatable alloys, so that it is necessary that the installation of the heat treatment facilities for producing the heat treatable sheets and plates should be considered from now by aluminum industries in Korea. Concerning the research activities on the aluminum sheets and plates in Korea, the research topics and contents are mainly concentrated on developing new high strength aluminum alloys for weight-reduction of the transportation systems. In order to keep up with aluminum manufacturing technologies of advanced countries, collaboration research works are also performed by several research groups. It is estimated that fruitful research results will be attained within two or three years from now.

Acknowledgments

The authors would like to express thanks to Dr. Y.H. Chung and Dr. J.W. Park of Korea Institute of Science and Technology and Prof. S.W. Nam of Korea Advanced Institute of Science and Technology for their valuable information.

References

1. K.C. Rhee and S.H. Ahn, Bull. of the Korean Inst. of Met. & Mater. **6**(2), 176 (1993).
2. Catalogue of and communication with Choil Aluminum Mfg. Co. Ltd.
3. Catalogue of and communication with Aluminum of Korea Ltd.
4. Catalogue of and communication with Taihan Electric Wire Co. Ltd., Youngju Plant.
5. M.C. Shin and Y.H. Chung, Summary intrim report of first stage HAN project related on developing high strength aluminum alloys, 1995.
6. M.J. Wheeler, Aluminum structured vehicles—The technology, the weight savings, the performance and value of such vehicles for the auto companies and their customers, Presentation to Washington, DC, Section of the SAE, 1995.
7. Y.L. Liu and S.B. Kang, Scripta Met. Mater. **30**, 487 (1994).
8. W.D. Fei and S.B. Kang, J. Mat. Sci. Letters **14**, 1795 (1995).

9. Y.L. Liu, S.B. Kang, H.K. Cho, and Z.Q. Hu, *Fourth Int. Conf. on Al Alloys* (Atlanta, Georgia, USA, 1994), p. 306.
10. H.W. Kim and S.B. Kang, *Second Pacific Rim Int. Conf. on Adv. Mat. & Proc.* (Kyongju, Korea, 1995), p. 2203.
11. W.D. Fei and S.B. Kang, Scripta Met. Mater. **34**, 357 (1996).
12. N.C. Kwon, C.S. Yoon, and H. Kang, Hyundai Automobile Co. Ltd., Interim Report, MOST, BSG 031-2117, 1995.
13. L. Zhen, S.B. Kang, H.W. Kim, and S.T. Lee, *Fifth Int. Conf. on Al Alloys* (Grenoble, France, 1996), p. 1031.
14. L. Zhen, S.B. Kang, and H.W. Kim, Scripta Met. Mater. **36**, 1089 (1997).
15. L. Zhen, W.D. Fei, S.B. Kang, and H.W. Kim, J. Mat. Sci. **32**, 1895–1902 (1997).
16. I.G. Moon, J.W. Park, and J.E. Yoo, Materials Science Forum **170–172**, 255–260 (1994), 1994 Trans Tech publication, Switzerland.
17. J.E. Yoo, J.W. Park, and I.G. Moon, Journal of the Korean Institute of Metals and Materials **30**(4), 454–461 (1992).
18. G.S. Kang, J.W. Park, I.G. Moom, D.H. Shin, and S.J. Maeng, Journal of the Korean Institute of Metals and Materials **30**(9), 1119–1126 (1992).
19. J.W. Park, H.S. Kim, I.G. Moon, K.Y. Ha, and D.Y. Lee, Korean Journal of Materials Research **5**(1), 132–139 (1995).
20. J.W. Park, I.G. Moon, and H.S. Kim, Development of superplastic aluminum alloy and superplastic forming technology (III), BSN1254-5519-1, MOST, Seoul, 1995.
21. J.W. Park, J.E. Yoo, and I.G. Moon, Journal of the Korean Institute of Metals and Materials **30**(2), 196–202 (1992).
22. I.G. Moon, J.W. Park, and J.E. Yoo, Grain refining and superplastic forming of aluminum alloys, UCN745(9)4251-1, MOST, Seoul, 1991.
23. Dong Nyung Lee, *Conference on Superplastic Forming* (Agency for Defence Development, Taejon, Korea, 1991).
24. H. Hub, *Conference on Superplastic Forming* (Agency for Defence Development, Taejon, Korea, 1991), chap. 3.
25. H. Osawa and H. Nishimura, Journal of Japan Institute of Light Metals **39**(11), 765–775 (1989).
26. H. Yoshida, H. Danaka, and S. Tsuchida, **29**(1), 58–68 (1988).
27. Y. Baba and H. Yoshida, Journal of the Japan Society for Technology of Plasticity (JSTP) **27**(302), 333–338 (1986-3).
28. R. Grimes and R.G. Butler, in *Superplasticity in Aerospace*, edited by H.C. Heikkenen and T.R. McNelley (The Metallurgical Society, 1988), pp. 97–113.
29. M. Matsuo, SKY aluminium Co., Ltd., 3–18 Nihombashi Muromachi 4-chome, Chuo-ku, Tokyo 103, Japan (1995).
30. B.J. Dunwoody, R. J. Stracey, and A.J. Barnes, Superplasticity in metals, ceramics and intermetallics, in *MRS Symp. Proc.*, edited by M.J. Mayo, M. Kobayashi, and J. Wadsworth (Materials Research Society, Pittsburgh, Pennsylvania, USA, 1990), vol. 196, pp. 161–166.
31. H. Watanabem, K. Ohori, and Y. Takeuchi, Trans. ISIJ **27**, 730–733 (1987).
32. K. Higashi, Journal of Japan Institute of Light Metals **39**(11), 751–764 (1989).