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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a process for manufacturing an aluminum alloy material for forming which has low anisotropy and excellent formability in press working, shape fixability and bake hardenability, and which is especially suitable for the manufacture of transport machinery, such as the body sheet material of automobiles.

2. Description of the Prior Art

Various types of aluminum alloys have heretofore been developed and used as the material of transport machinery, such as the body sheet material of automobiles. Especially, in recent years, a tendency toward using aluminum alloys instead of steel materials to obtain a light-weight structure with respect to various parts has been very conspicuous in order to comply with the tightening of legal regulations established as countermeasures against earth warming.

For example, it is necessary that the body sheet materials of automobiles satisfy requirements for (1) formability, (2) shape fixability (accurate reproduction of the shape of press dies in press working), (3) high strength, (4) dentability, and (5) corrosion resistance. etc.

Under these circumstances, in Japan, where the requirements from the press work industry are strict, the development of body sheet materials of automobiles or the like has mainly been directed to 5000 series Al-Mg-Zn-Cu alloys (see Japanese Patent Application Laid-Open Nos. 103914/1978 and 171547/1983) and Al-Mg-Cu alloys (see Japanese Patent Application Laid-Open No. 219139/1989) having excellent formability.

By contrast, in the United States and Europe, 6009, 6111 and 6016 alloys have been developed as 6000 series Al-Mg-Si alloys having high strength. These alloys acquire high strength by heat treatment at 200 °C for about 30 minutes during the paint bake step, so that the attainment of a marked decrease in thickness, i.e., the attainment of a light-weight structure, is feasible.

However, in Japan, a lower paint bake temperature, such as about 170 °C, which is usually employed for steel, is required, so that it is unexpected to achieve a high strength by 30-minute heating with the current alloys or the current manufacturing process. Moreover, the current alloys suffer from room temperature age hardening, and have problems of their formability being poor and their corrosion resistance being relatively low. Therefore, in Japan, where the requirements for various performances are strict, the 6000 series alloys have no advantage over the 5000 series alloys, and have never been employed.

On the other hand, shape fixability can be improved as elastic modulus is increased and yield strength is decreased (see SAE Paper No. 890719). Because the elastic modulus of an aluminum alloy is 7000 kgf/mm^2, which is about one third of 21,000 kgf/mm^2 for steel, it is impossible to obtain a material having the same shape fixability as that of a steel sheet, unless the yield strength of the aluminum alloy sheet in press working is considerably lowered. According to the experiments of the present inventors, it is desirable that the yield strength be lower than 14 kgf/mm^2. However, when it is intended to obtain a structure having a tensile strength of about 30 kgf/mm^2, which is comparable to that of a steel sheet, the yield strength of the aluminum alloy sheet manufactured by the conventional method is inevitably increased to about 14 kgf/mm^2 or above in both the 5000 series alloy and the 6000 series alloy, which is likely to give rise to a poor shape fixability.

Therefore, all of the above-mentioned problems can be solved by lowering the yield strength before pressing far below 14 kgf/mm^2 so as to improve the shape fixability and conducting the paint bake at about 170 °C for 30 minutes so as to markedly increase the yield strength and the tensile strength and to improve the dentability and the structural strength. However, no conventional alloys manufactured by the conventional method can provide such a solution.

SUMMARY OF THE INVENTION

Accordingly, the present invention provides a material especially suitable for press working which has its room temperature age hardening properties suppressed so as to improve its formability and exhibits improved shape fixability and excellent bake hardenability, as a result of detailed studies of chemical compositions and thermomechanical treatment.

The present invention provides a process for manufacturing an aluminum alloy for forming which has excellent formability, shape fixability and bake hardenability and, which comprises the steps of:

conducting semi-continuous casting of an alloy comprising, in weight percentages, from 0.4% to less than 1.5% Si and from 0.3% to less than 0.5% Mg and, optionally further comprising at least one member selected from the group consisting of up to 0.20% Cu, up to 0.20% Mn and up to 0.20% Cr with the balance consisting of Al, to prepare an ingot;

rolling the ingot to a final sheet thickness according to conventional techniques;

conducting solution heat treatment by heating the sheet at a heating rate of 100 °C/min or higher to a temperature of from 450 °C to below 580 °C and holding the sheet in this temperature range for a period of from 10 seconds to less than 10 minutes;

cooling the sheet to 150 °C or below at a cooling rate of 100 °C/min or higher;

maintaining at room temperature for less than 60 minutes; and

maintaining the sheet at a temperature of from 50 °C to 150 °C for a period of from 10 minutes to 500 minutes.

In another aspect of the present invention, V is further added, as an essential component, in an amount of 0.02% to 0.2% to the above-specified alloy composition with the object of reducing its anisotropy.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The reason for the above-described limitations of the components in the alloy of the present invention will now be described.

Si: It is needed to obtain a high strength and form Mg_2Si so as to provide a high strength. When the amount thereof is less than 0.4%, satisfactory strength will not be obtained, even when a paint bake heating is conducted. On the other hand, when the Si amount is 1.5% or above, the yield strength is too high after the solution heat treatment or the completion of final heat treatment, and the formability and the shape fixability are poor.

Mg: It is needed to obtain a high strength.

When the amount of Mg is less than 0.3%, satisfactory strength will not be obtained, even when paint bake heating is conducted. On the other hand, when the Mg amount is 0.5% or above, the yield strength is too high after the solution heat treatment or the completion of final heat treatment, and the formability and the shape fixability are poor.

V: Its addition contributes to a further increase in the strength and an improvement in the isotropy of the mechanical properties. However, when the amount thereof is less than 0.02%, no effect is exhibited. On the other hand, when the amount of addition of V exceeds 0.2%, the yield strength is too high after the solution heat treatment or the completion of final heat treatment, and the formability and the shape fixability are poor.

Cu: Its addition contributes to a further increase in the strength. However, when the amount of Cu addition exceeds 0.20%, the yield strength is too high after the solution heat treatment or the completion of final heat treatment, and not only the formability and the shape fixability but also the resistance to filiform corrosion are poor.

Mn: Its addition contributes to a further increase in the strength and makes the grains finer so as to improve the formability. However, when the amount of addition exceeds 0.20%, the yield strength is too high after the solution heat treatment or the completion of final heat treatment and, not only are the formability and the shape fixability poor, the amount coarse intermetallic compounds increase so as to lower the formability.

Cr: Its addition contributes to a further increase in the strength and makes the grains finer so as to improve the formability. However, when the amount of addition exceeds 0.20%, the yield strength is too high after the solution heat treatment or the completion of final heat treatment, and not only the formability and the shape fixability are poor but also coarse intermetallic compounds are increased so as to lower the formability.

The reason for the above-described limitations of the treatment conditions will now be described.

Solution heat treatment: When the heating rate is below 100 °C/min, grains become so coarse that the formability is poor. Further, when the heating temperature is below 450 °C, the dissolution of precipitates is unsatisfactory and satisfactory strength cannot be obtained after the paint bake. On the other hand, when the temperature is 580 °C or above, eutectic melting occurs to thereby lower the formability. Additionally, when the holding time at 450 °C or above is less than 10 seconds, the dissolution of precipitates is unsatisfactory and satisfactory strength cannot be obtained after paint bake. On the other hand, a holding time of 10 minutes or more does not bring about any further improvement in the performances, so that it is less valuable from the industrial viewpoint.

Cooling step: The rate of cooling down to 150 °C or below after the solution heat treatment should be 100 °C/min or higher. When the cooling rate is less than 100 °C/min, coarse intermetallic compounds precipitate along the grain boundaries so as to lower the ductility and lead to poor formability.

Holding time at room temperature: Preferably, the holding time of the sheet at room temperature should be as short as possible. The allowable time is less than 60 minutes. When the holding time is 60 minutes or longer, GP zones grow and the decomposition of the GP zones take a long time, even when baking is conducted at about 170 °C after pressing, which renders hardening difficult.

Final heat treatment after holding at room temperature: When the sheet is held at a temperature of from 50 °C to 150 °C for a period of from 10 minutes to 500 minutes after being maintained at this temperature for a period of less than 60 minutes, clusters form. This serves to suppress the room temperature age hardening due to the formation of GP zones so as to maintain excellent formability, and allows curing to take place in a short time upon heating to about 170 °C during the paint bake. When the temperature is below 50 °C or exceeds 150 °C and the holding time is less than 10 minutes or exceeds 500 minutes, the formation of clusters is unsatisfactory and hardening becomes difficult during the paint bake.

Example 1

Each alloy listed in Table 1 semicontinuously cast and the surface of the ingot was scalped. Subsequently, the alloy was homogenized at 550 °C for 24 hours, and the temperature was then allowed to fall to 500 °C. Hot rolling was started at that temperature, and the alloy was rolled to a thickness of 5 mm. Then, the hot rolled alloy was subjected to intermediate annealing at 350 °C for 1 hour in a batch furnace and cold-rolled to prepare a sheet having a thickness of 1 mm. The sheet was subjected to solution heat treatment under the conditions specified in Table 2 in a continuous annealing line, cooled, maintained at a predetermined room temperature, subjected to final heat treatment under the conditions specified in Table 2, and levelled. The mechanical properties of the obtained materials were evaluated after aging at room temperature for one month subsequent to the final heat treatment.

The results of the evaluation of the materials tested are given in Table 3. Materials having a yield strength of 13.5 kgf/mm^2 or less after the one-month room temperature age hardening were deemed as having an excellent shape fixability. Materials having an elongation of 28% or more and an Erichsen value of 9.5 mm or more were deemed as having an excellent formability. Materials exhibiting a yield strength increase of 5 kgf/mm^2 or more after heat treatment at 170 °C for 30 minutes, even subsequent to the one-month room temperature age hardening, were deemed as having an excellent bake hardenability. Materials exhibiting a yield strength increase of 13.5 kgf/mm^2 or more after heat treatment at 170 °C for 30 minutes, even subsequent to the one-month room temperature age hardening, were deemed as having excellent dentability. Materials satisfying all of the above criteria were deemed as acceptable. With respect to the grain diameter, the sheet surface was observed and materials having a grain diameter of 100 μm or less were deemed as acceptable.

All of the materials of Examples 1 to 8 of the present invention fall within the scope of the claims and exhibit excellent properties.

The materials of Comparative Examples 1 and 2 exhibited a low yield strength even after heating at 170 °C for 30 minutes, because the material of Comparative Example 1 had an Si content lower than that defined in the claims and the material of Comparative Example 2 had an Mg content lower than that defined in the claims. The Si content and Mg content of the material of Comparative Example 3, the Cu content of the material of Comparative Example 4, the Mn content of the material of Comparative Example 5 and the Mn content and Cr content of the material of Comparative Example 6 were higher than the respective content ranges defined in the claims, and these materials exhibited yield strengths that were too high after the final heat treatment and yield strengths exceeding 13.5 kgf/mm^2 after the one-month room temperature age hardening, so that their shape fixability and formability were poor. In the material of Comparative Example 7, since the heating rate to the solution heat treatment was low, the grain became coarse. Further, since the cooling rate was low, the precipitation at the grain boundary was so remarkable that the elongation was small and the formability was poor. In the material of Comparative Example 8, since the holding time at a temperature of 450 °C or above was short, the increase after paint bake in the yield strength was small. In the material of Comparative Example 9, since the solution heat treatment temperature was so high that eutectic melting and sheet breaking occurred. Therefore, the subsequent heat treatment and evaluations were halted. In the material of Comparative Example 10, since the holding time in the final heat treatment was shorter than the lower limit defined in the claims, not only did the room temperature age hardening give a yield strength exceeding 13.5 kgf/mm^2 and lower the shape fixability but also the increase in the strength after heating at 170 °C was small. In Comparative Example 11, since the material was maintained at room temperature without a predetermined final heat treatment after the solution heat treatment according to the conventional process, as in Comparative Example 10, the room temperature age hardening could not be suppressed and the increase in the strength after heating at 170 °C was small. In the material of Comparative Example 12, since the holding temperature in the final heat treatment was higher than the upper limit defined in the claims, the material was hardened unfavourably and good formability was not obtained.

Table 1

(wt%)

	Sample No.	Si	Mg	Cu	Mn	Cr	Fe	Ti	Al
Ex. of present invention	1	1.05	0.45	0.04	<0.01	<0.01	0.04	0.02	bal.
	2	0.81	0.45	<0.01	<0.01	<0.01	0.07	0.01	bal.
	3	0.81	0.45	<0.01	0.05	<0.01	0.05	0.01	bal.
	4	1.32	0.41	<0.01	<0.01	<0.01	0.10	0.01	bal.
	5	1.21	0.48	0.03	0.05	<0.01	0.08	0.01	bal.
	6	0.43	0.45	0.15	0.12	0.04	0.07	0.01	bal.
	7	0.94	0.32	<0.01	<0.01	<0.01	0.07	0.01	bal.
	8	0.88	0.39	<0.01	<0.01	0.11	0.07	0.01	bal.
Comp. Ex.	1	0.35	0.45	0.02	0.05	<0.01	0.07	0.01	bal.
	2	0.83	0.26	<0.01	<0.01	<0.01	0.07	0.01	bal.
	3	1.62	0.56	<0.01	<0.01	<0.01	0.07	0.01	bal.
	4	1.35	0.46	0.28	<0.01	<0.01	0.07	0.01	bal.
	5	1.35	0.46	0.05	0.31	0.04	0.07	0.01	bal.
	6	1.35	0.46	0.05	0.25	0.23	0.07	0.01	bal.
	7	1.13	0.47	<0.01	<0.01	<0.01	0.07	0.01	bal.
	8	1.13	0.47	<0.01	<0.01	<0.01	0.07	0.01	bal.
	9	1.13	0.47	<0.01	<0.01	<0.01	0.07	0.01	bal.
	10	1.13	0.47	<0.01	<0.01	<0.01	0.07	0.01	bal.
	11	1.13	0.47	<0.01	<0.01	<0.01	0.07	0.01	bal.
	12	1.13	0.47	<0.01	<0.01	<0.01	0.07	0.01	bal.

Table 2

		Solution treatment conditions			Cooling rate °C/min	holding at room temp. after solution treatment	Final heat treatment
		heating rate, °C/min	time taken for the temp. to exceed 450°C and reach holding temp.	holding temp. and time			
Ex. of present invention	1	1000	10s	550°C-10s	900	-5°C-40min	60°C-300min
	2	500	10s	550°C-10s	500	25°C-15min	100°C-150min
	3	800	10s	510°C-0s	700	35°C-10min	90°C-200min
	4	400	20s	550°C-0s	500	20°C-10min	110°C-80min
	5	500	20s	550°C-10s	700	25°C-5min	90-100°C -100min
	6	200	4min	500°C-2min	150	25°C-5min	90°C-200min
	7	500	25s	570°C-10s	500	25°C-5min	110°C-80min
	8	500	10s	500°C-10s	450	25°C-5min	130°C-15min
Comp. Ex.	1	400	20s	550°C-0s	500	20°C-20min	110°C-80min
	2	400	20s	550°C-0s	500	20°C-20min	110°C-80min
	3	400	20s	550°C-0s	500	20°C-20min	110°C-80min
	4	400	20s	550°C-0s	500	20°C-20min	110°C-80min
	5	400	20s	550°C-0s	500	20°C-20min	110°C-80min
	6	400	20s	550°C-0s	500	20°C-20min	110°C-80min
	7	30	5min	550°C-1min	50	20°C-20min	110°C-80min
	8	400	5s	455°C-0s	500	20°C-20min	110°C-80min
	9	400	40s	600°C-5s	500	evaluation was halted due to eutectic melting	
	10	400	20s	550°C-0s	500	20°C-5min	100°C-5min
	11	400	20s	550°C-0s	500	20°C-1month	-
	12	400	20s	550°C-0s	500	20°C-5min	160°C-2min

Table 3

Sample No.		Mechanical properties of material subjected to final heat treatment: after one day $\sigma_{0.2}$ (kgf/mm²)	after one-month room temp. age hardening: $\sigma_{0.2}$ (kgf/mm²)	after one-month room temp. age hardening: σ_B (kgf/mm²)	after one-month room temp. age hardening: δ (%)	after one-month room temp. age hardening: Ev (mm)	After heating at 170°C for 30 min subsequent to one-month room temp. age hardening $\sigma_{0.2}$ (kgf/mm²)	Grain diameter (μm)
Ex. of present invention	1	11.0	11.1	20.7	30	10.1	18.6	22
	2	10.9	11.1	21.1	30	10.0	20.4	30
	3	10.7	10.9	20.0	30	10.0	19.3	22
	4	12.6	12.7	25.6	31	10.2	21.6	26
	5	13.1	13.2	26.3	31	10.1	22.5	22
	6	8.5	8.7	17.1	32	10.5	13.9	25
	7	10.1	10.1	19.5	30	10.1	16.5	26
	8	11.3	11.5	20.2	31	10.3	17.5	19
Comp. Ex.	1	7.5	7.5	16.4	31	10.2	11.9	26
	2	7.9	8.0	16.9	32	10.3	12.1	26
	3	15.3	15.5	27.9	28	9.5	23.0	30
	4	14.8	14.9	27.9	28	9.7	24.1	19
	5	14.7	14.8	27.5	27	9.5	24.0	13
	6	15.2	15.4	28.0	27	9.3	23.1	13
	7	12.5	12.7	25.9	23	9.0	20.7	120
	8	13.2	13.5	23.4	25	9.2	16.4	16
	9	-	-	-	-	-	-	-
	10	13.5	14.3	26.9	29	9.9	17.8	22
	11	13.6	14.5	27.0	29	9.9	15.0	22
	12	15.1	15.2	27.3	25	9.4	15.4	22

Note: Ev refers to the Erichsen value.

Example 2

Each alloy listed in Table 4 was semicontinuously cast and the surface of the ingot scalped. Subsequently, the alloy was homogenized at 550 °C for 24 hours and the temperature allowed to fall to 500 °C. Hot rolling was started at that temperature and the alloy was rolled to a thickness of 2 mm. Then, the hot rolled alloy was subjected to solution heat treatment under the conditions specified in Table 5 in a continuous annealing line, cooled, maintained at a predetermined room temperature, subjected to final heat treatment under the conditions specified in Table 5, and levelled.

The results of the evaluation of the materials tested are given in Table 6. The criteria of the evaluation and judgment on the acceptability of each material were the same as those of Example 1.

All of the materials of Examples 9 to 13 of the present invention fall within the scope of the claims and exhibit excellent performances.

In the material of Comparative Example 13, since the Si content and Mg content were lower than the respective lower limits defined in the claims, the strength was low even after heating at 170 °C for 30 minutes. In the materials of Comparative Examples 14 and 15, since the Si content of Comparative Example 14 and the Mg content of Example 15 were higher than the respective upper limits defined in the claims, the shape fixability was poor due to an excessively high yield strength and the formability was poor due to low elongation and Erichsen value. In the material of Comparative Example 16, since the heating rate to the solution heat treatment was low, the grain became coarse. Further, since the cooling rate was low, the precipitation at the grain boundary was so remarkable that the elongation and Erichsen value were low. In Comparative Example 17, since the material was held at 20 °C for a period of time as long as 100 minutes between the solution heat treatment and the final heat treatment, a large number of GP zones were formed and high strength could not be obtained, even when the material was heated at 170 °C for 30 minutes. In the material of Comparative Example 18, since the final heat treatment was so short that the formation of clusters was insufficient and the formability slightly lowered due to the progress of the room temperature age hardening after the heat treatment. Further, high strength could not be obtained even when the material was heated at 170 °C. In the material of Comparative Example 19, the final heat treatment temperature was so high that the formability lowered due to the hardening of the material.

Table 4

(wt%)

Sample No.		Si	Mg	Cu	Mn	Cr	Fe	Ti	Al
Ex. of present invention	9	1.43	0.39	<0.01	0.06	<0.01	0.03	0.01	bal.
	10	0.97	0.45	0.03	<0.01	<0.01	0.06	0.02	bal.
	11	1.13	0.42	<0.01	<0.01	<0.01	0.06	0.01	bal.
	12	0.67	0.48	<0.01	<0.01	<0.01	0.06	0.01	bal.
	13	0.91	0.36	<0.01	<0.01	<0.01	0.06	0.01	bal.
Comp. Ex.	13	0.36	0.28	0.02	<0.01	<0.01	0.07	0.01	bal.
	14	1.73	0.43	<0.01	<0.01	<0.01	0.07	0.01	bal.
	15	1.32	0.74	<0.01	<0.01	<0.01	0.07	0.01	bal.
	16	0.97	0.45	0.03	<0.01	<0.01	0.06	0.01	bal.
	17	0.97	0.45	0.03	<0.01	<0.01	0.06	0.01	bal.
	18	0.97	0.45	0.03	<0.01	<0.01	0.06	0.01	bal.
	19	0.97	0.45	0.03	<0.01	<0.01	0.06	0.01	bal.

Table 5

		Solution treatment conditions			Cooling rate °C/min	Holding at room temp. after solution treatment	Final heat treatment
		heating rate, °C/min	time taken for the temp to exceed 450°C and reach holding temp.	holding temp. and time			
Ex. of present invention	9	300	30s	540°C-10s	300	15°C-5min	120°C-30min
	10	300	30s	540°C-10s	300	25°C-5min	80°C~ 100°C -200min
	11	300	30s	540°C-10s	300	35°C-10min	90°C-200min
	12	400	20s	530°C-5s	300	35°C-10min	90°C-200min
	13	300	10s	500°C-0s	300	35°C-10min	90°C-200min
Comp. Ex.	13	300	30s	540°C-10s	300	25°C-5min	90°C-200min
	14	300	30s	540°C-10s	300	25°C-5min	90°C-200min
	15	300	30s	540°C-10s	300	25°C-5min	90°C-200min
	16	40	50s	560°C-3min	70	25°C-5min	90°C-200min
	17	300	30s	530°C-5s	300	20°C-100min	90°C-200min
	18	300	30s	530°C-5s	300	15°C-15min	90°C-5min
	19	300	30s	530°C-5s	300	15°C-15min	190°C-30min

Table 6

Sample No.		Mechanical properties of material subjected to final heat treatment: after one day $\sigma_{0.2}$ (kgf/mm²)	Mechanical properties of material subjected to final heat treatment: after one-month room temp. age hardening $\sigma_{0.2}$ (kgf/mm²)	after one-month room temp. age hardening σ_B (kgf/mm²)	after one-month room temp. age hardening δ (%)	after one-month room temp. age hardening Ev (mm)	After heating at 170°C for 30 min subsequent to one-month room temp. age hardening $\sigma_{0.2}$ (kgf/mm²)	grain diameter (μm)
Ex. of present invention	9	13.2	13.4	26.8	31	10.5	21.5	19
	10	11.1	11.2	19.8	31	10.3	18.1	26
	11	13.1	13.2	26.7	30	10.2	20.4	22
	12	9.7	9.9	17.8	30	10.3	19.8	22
	13	11.0	11.1	19.9	30	10.0	17.5	22
Comp. Ex.	13	6.8	6.9	15.4	31	10.9	10.9	26
	14	14.8	14.9	27.1	25	9.1	22.8	26
	15	15.1	15.1	27.4	24	9.0	23.0	26
	16	11.5	11.5	19.7	21	8.9	12.1	110
	17	12.5	12.7	20.5	29	10.1	14.1	22
	18	12.0	12.6	20.4	30	10.1	15.4	22
	19	15.1	15.1	27.9	24	9.0	15.1	22

Note: Ev refers to the Erichsen value.

Example 3

Each of the alloys listed in Table 7 was semicontinuously cast, and scalping was conducted on the cast surface. The Fe and Ti listed in Table 7 are impurities. Subsequently, homogenizing treatment was performed at 550 °C for 24 hours, and the temperature was decreased to 520 °C, at which hot rolling was started. The rolling was conducted to obtain a thickness of 5 mm, followed by intermediate annealing at 350 °C for 1 hour in a batch furnace. Cold rolling was performed to prepare a sheet having a thickness of 1 mm. The sheet was subjected to solution heat treatment in a continuous annealing line under the conditions specified in Table 8, cooled, and maintained at a predetermined room temperature. Thereafter, final heat treatment was performed under the conditions specified in Table 8. The evaluation of the mechanical properties of the resultant materials were conducted after one-month room temperature age hardening subsequent to the final heat treatment.

The evaluation results of sample materials are given in Table 9. The evaluation of each material and the judgment on their acceptability were performed as follows. Materials having a yield strength of 13.5 kgf/mm^2 or less after the one-month room temperature age hardening were deemed as having an excellent shape fixability. Materials having an elongation of 28% or more and an Erichsen value of 9.5 mm or more were deemed as having an excellent formability. Materials having a difference of 2% or less between the elongation of the specimen taken parallel to the rolling direction and that taken perpendicular to the rolling direction were deemed as having less anisotropy. Materials exhibiting a yield strength increase of 5 kgf/mm^2 or more after heat treatment at 170 °C for 30 minutes, even subsequent to the one-month room temperature age hardening, were deemed as having an excellent bake hardenability. Materials exhibiting a yield strength increase of 13.5 kgf/mm^2 or more after heat treatment at 170 °C for 30 minutes, even subsequent to the one-month room temperature age hardening, were deemed as having excellent dentability. Materials satisfying all of the above criteria were deemed as acceptable. With respect to the grain diameter, the sheet surface was observed, and materials having a grain diameter of 100 µm or less were deemed as acceptable.

All of the materials of Examples 14 to 21 of the present invention fall within the scope of the claims for patent and exhibit excellent properties.

The alloying components of the materials of Comparative Examples 20 to 29 were within the scope of claims for patent but the final heat treatment conditions were outside the scope of the present invention.

The material of Comparative Example 20 had poor formability, because the heating rate to the solution heat treatment was lower than that defined in the claims so that grains become coarse. The material of Comparative Example 21 was inferior in both formability and bake hardenability because the cooling rate in the solution heat treatment was lower than that defined in the claims so that solute atoms were precipitated on the grain boundaries to thereby diminish the hardening effect. The materials of Comparative Examples 22 and 23 had poor bake hardenability because the former had a holding temperature in the solution heat treatment of below that defined in the claims for patent and the latter had a holding time in solution heat treatment of shorter than that defined in the claims for patent, resulting in an insufficient solution heat treatment. The evaluation of the material of Comparative Example 24 was halted because the temperature in the solution heat treatment was so high that partial eutectic melting occurred.

The materials of Comparative Examples 25 and 26 had poor bake hardenability because the former had a room temperature holding time after the solution heat treatment of longer than that defined in the claims for patent and the latter had a final heat treatment time of shorter than the lower limit of that defined in the claims for patent. The materials of Comparative Examples 27 and 28 were inferior in both bake hardenability and formability because the former had a final heat treatment time of longer than the upper limit of that defined in the claims for patent and the latter had a final heat treatment temperature of higher than the upper limit of that defined in the claims for patent. The material of Comparative Example 29 had an inferior bake hardenability because the final heat treatment temperature is lower than the lower limit of that defined in the claims for patent.

In Comparative Examples 30 to 35, the heat treatment conditions were within the scope of the present invention but alloy components were not.

The materials of Comparative Examples 30 and 31 were inferior in both bake hardenability and dentability because the former contained Si in an amount smaller than the lower limit of that defined in the claims for patent and the latter contained Mg in an amount less than the lower limit of that defined in the claims for patent. In the material of Comparative Example 31, an anisotropy was observed in the mechanical properties because the content of V was less than the lower limit of that defined in the claims for patent. Each of the materials of Comparative Examples 32 to 35 exhibited too high a yield strength after the one-month room temperature age hardening and were inferior in both shape fixability and formability because the materials of Comparative Example 32 contained Si in an amount greater than the upper limit of that defined in the claims for patent, the material of Comparative Example 33 contained Cu in an amount greater than the upper limit of that defined in the claims for patent, the material of Comparative Example 34 contained Mn and Cr in amounts greater than the upper limits of those defined in the claims for patent, and the material of Comparative Example 35 contained V in an amount greater than the upper limit of that defined in the claims for patent.

In the above Examples, when no V was added, the yield strength and the tensile strength of the specimen taken perpendicular to the rolling direction were high while the elongation was low, although the situation may be reversed depending on the manufacturing processes.

Table 7

Alloy No.		Si	Mg	V	Cu	Mn	Cr	Fe	Ti	Al
Ex. of present invention	A	1.2	0.45	0.05	0.15	<0.01	<0.01	0.14	0.02	bal.
	B	0.82	0.49	0.08	<0.01	<0.01	<0.01	0.05	0.01	bal.
	C	0.84	0.42	0.10	<0.01	0.05	<0.01	0.12	0.01	bal.
	D	1.4	0.44	0.10	<0.01	<0.01	<0.01	0.10	0.01	bal.
	E	0.63	0.39	0.10	0.04	0.06	<0.01	0.10	0.01	bal.
	F	0.72	0.41	0.10	<0.01	0.13	0.04	0.10	0.01	bal.
	G	0.91	0.44	0.15	<0.01	<0.01	<0.01	0.05	0.01	bal.
	H	1.3	0.45	0.10	<0.01	<0.01	0.12	0.21	0.01	bal.
Comp. Ex.	I	0.32	0.40	0.05	0.02	0.05	<0.01	0.10	0.01	bal.
	J	0.85	0.20	<0.01	<0.01	<0.01	<0.01	0.10	0.01	bal.
	K	1.8	0.49	0.10	<0.01	<0.01	<0.01	0.10	0.01	bal.
	L	1.4	0.45	0.08	0.35	<0.01	<0.01	0.10	0.01	bal.
	M	1.4	0.48	0.10	0.05	0.32	0.24	0.10	0.01	bal.
	N	1.4	0.48	0.32	0.05	0.13	0.10	0.10	0.01	bal.

Note: wt.%

Table 8

Heat treatment condition		Solution heat treatment conditions: heating rate, °C/min	Solution heat treatment conditions: holding condition	Cooling rate °C/min	Holding at room temp. after solution heat treatment	Final heat treatment
Ex. of present invention	A	800	550°C - 10s	800	25°C - 40 min	60°C - 300 min
	B	500	550°C - 10s	500	25°C - 15 min	100°C - 150 min
	C	400	550°C - 5s	500	20°C - 10 min	110°C - 80 min
	D	500	550°C - 10s	700	25°C - 5 min	90°C - 100 min
	E	200	500°C - 2 min	150	25°C - 5 min	90°C - 200 min
	F	500	500°C - 10s	450	25°C - 5 min	130°C - 15 min
Comp. Ex.	G	30	550°C - 1 min	300	20°C - 20 min	110°C - 80 min
	H	400	550°C - 1 min	50	20°C - 20 min	110°C - 80 min
	I	400	430°C - 1 min	300	20°C - 20 min	110°C - 80 min
	J	400	450°C - 5s	300	20°C - 20 min	110°C - 80 min
	K	400	600°C - 20s	300	20°C - 20 min	110°C - 80 min
	L	400	550°C - 5s	500	20°C - 80 min	110°C - 80 min
	M	400	550°C - 5s	500	20°C - 20 min	110°C - 5 min
	N	400	550°C - 5s	500	20°C - 20 min	110°C - 900 min
	O	400	550°C - 5s	500	20°C - 5 min	170°C - 20 min
	P	400	550°C - 5s	500	20°C - 5 min	40°C - 400 min

Note: * heating rate in the solution heat treatment condition: average heating rate from room temperature to holding temperature.

* Cooling rate after solution heat treatment average cooling rate from holding temperature to 150°C or below.

Table 9

Heat treatment conditions	Sample No.	Alloy		Mechanical properties of material subjected to final heat treatment: after one day, parallel to the rolling direction $\sigma_{0.2}$ (kgf/mm²)	One-month room temperature age hardening, parallel to the rolling direction $\sigma_{0.2}$ (kgf/mm²)	σ_B (kgf/mm²)	δ (%)	Perpendicular to the rolling direction $\sigma_{0.2}$ (kgf/mm²)	σ_B (kgf/mm²)	δ (%)	Ev*1 (mm)	Parallel to the*2 rolling direction $\sigma_{0.2}$ (kgf/mm²)	Crystal grain diameter (µm)
Ex. of present invention	14	A	A	12.8	13.0	24.7	30	12.8	24.5	30	10.1	20.6	35
	15	B	B	10.9	11.0	22.5	29	11.1	22.1	30	10.0	17.2	40
	16	C	B	11.6	11.7	23.0	31	11.9	22.9	30	10.0	18.3	28
	17	D	B	12.6	13.2	26.2	31	12.9	25.8	29	10.2	21.6	40
	18	E	C	9.5	9.5	20.2	32	9.6	20.3	31	10.8	16.5	30
	19	F	D	10.5	10.6	20.8	31	10.5	20.9	32	10.4	17.9	26
	20	G	E	11.1	11.3	21.6	31	11.1	21.5	30	10.4	20.0	35
	21	H	F	13.0	13.2	25.2	32	13.1	24.9	31	10.2	22.1	40
	20	A	G	2.8	12.9	22.3	27	12.9	22.0	25	8.9	20.8	130
	21	A	H	10.8	10.9	19.3	23	10.9	19.0	22	8.5	13.8	40
	22	A	I	12.5	12.6	21.4	27	12.7	21.4	25	8.5	12.7	50
	23	A	J	12.3	12.5	21.3	25	12.5	21.5	26	8.4	12.5	50
	24	A	K	evaluation was halted due to eutectic melting									
Com. Ex.	25	A	L	13.0	13.2	23.5	29	13.2	23.6	30	10.3	14.5	35
	26	A	M	13.1	13.2	23.6	30	13.3	23.5	30	10.9	14.8	30
	27	A	N	15.1	15.1	24.0	26	15.1	24.1	26	9.0	19.5	30
	28	A	O	15.3	15.3	25.3	25	15.4	26.0	26	8.8	19.4	45
	29	A	P	13.0	13.1	23.2	30	13.2	23.4	31	9.8	14.7	30
	30	I	C	7.8	8.0	17.5	30	8.8	18.2	26	9.8	11.2	55
	31	J	C	9.2	9.4	18.2	31	9.3	18.4	26	9.5	12.0	26
	32	K	C	14.2	14.3	24.3	30	14.3	24.1	30	9.2	22.3	35
	33	L	C	13.9	14.0	24.2	31	14.6	24.8	30	9.1	20.1	35
	34	M	C	15.1	15.3	24.9	29	15.7	25.5	28	8.9	23.2	35
	35	N	C	13.8	13.9	24.1	30	14.0	24.5	31	9.0	21.7	26

Remarks *1: Erichsen value
*2: After heating at 170°C for 30 min subsequent to one-month room temp. age hardening

The present invention can provide a material for press which has improved formability by virtue of having suppressed room temperature age hardening, improved shape fixability and excellent bake hardenability. Further, it becomes possible to manufacture various forming materials each having a smaller thickness than that of the conventional forming material so that the reduction in the weight of the formed article can be further promoted. Although the present invention has been described mainly by examples of the sheet material, it can be applied also to other manufacturing processes, such as a process for manufacturing an extruded material, because the alloy used can be manufactured by the same principles.

Further, even though the paint bake temperature may be lowered to 150 °C or below in the near future, the effects attained by heating at 170 °C cannot be expected at that temperature. However, according to the present invention, the performance of the product is clearly superior to that of the prior art.

Claims

1. A process for manufacturing an aluminum alloy material with excellent formability, shape fixability and bake hardenability, the process comprising the steps of:

   conducting semicontinuous casting of an alloy comprising, in weight percentage, from 0.4% to less than 1.5% of Si, from 0.3% to less than 0.5% of Mg with the balance consisting of Al and unavoidable impurities to prepare an ingot;

   rolling the ingot to a final sheet thickness according to the conventional technique;

   conducting solution heat treatment by heating the sheet at a heating rate of 100° C/min or above to 450 °C or above but below 580 °C and holding the sheet in this temperature range for a period of from 10 seconds to less than 10 minutes;

   cooling the sheet to 150 °C or below at a cooling rate of 100 °C/min or above;

   allowing the sheet to hold still at room temperature for a period of less than 60 minutes; and

   holding the sheet at a temperature of from 50 °C to 150 °C for a period of from 10 minutes to 500 minutes.

2. A process for manufacturing an aluminum alloy material with formability, shape fixability and bake hardenability, the process comprising the steps of:

   conducting semicontinuous casting of an alloy comprising, in weight percentage, from 0.4% to less than 1.5% of Si and from 0.3% to less than 0.5% of Mg and further comprising at least one member selected from the group consisting of up to 0.20% of Cu, up to 0.20% of Mn and up to 0.20% of Cr with the balance consisting of Al and unavoidable impurities to prepare an ingot;

   rolling the ingot to a final sheet thickness according to the conventional technique;

   conducting solution heat treatment by heating the sheet at a heating rate of 100 °C/min or above to 450 °C or above but below 580 °C and holding the sheet in this temperature range for a period of from 10 seconds to less than 10 minutes;

   cooling the sheet to 150 °C or below at a cooing rate of 100 °C/min or above;

   allowing the sheet to hold still at room temperature for less than 60 minutes; and

   holding the sheet at a temperature of from 50 °C to 150 °C for a period of from 10 minutes to 500 minutes.

3. A process for manufacturing an aluminum alloy material with less anisotropy and excellent formability, shape fixability and bake hardenability, the process comprising the steps of:

   conducting semicontinuous casting of an alloy comprising, in weight percentage, from 0.4% to less than 1.5% of Si, from 0.3% to less than 0.5% of Mg and from 0.02% to 0.2% of V with the balance consisting of Al and unavoidable impurities to prepare an ingot;

   rolling the ingot to a final sheet thickness according to the conventional technique;

   conducting solution heat treatment by heating the sheet at a heating rate of 100° C/min or above to 450 °C or above but below 580 °C and holding the sheet in this temperature range for a period of from 10 seconds to less than 10 minutes;

   cooling the sheet to 150 °C or below at a cooling rate of 100 °C/min or above;

   allowing the sheet to hold still at room temperature for a period of less than 60 minutes; and

   holding the sheet at a temperature of from 50 °C to 150 °C for a period of from 10 minutes to 500 minutes.

4. A process for manufacturing an aluminum alloy material with less anisotropy and excellent formability, shape fixability and bake hardenability, the process comprising the steps of:

   conducting semicontinuous casting of an alloy comprising, in weight percentage, from 0.4% to less than 1.5% of Si, from 0.3% to less than 0.5% of Mg and from 0.02% to 0.2% of V and further comprising at least one member selected from the group consisting of up to 0.20% of Cu, up to 0.20% of Mn and up to 0.20% of Cr with the balance consisting of Al and unavoidable impurities to prepare an ingot;

   rolling the ingot to a final sheet thickness according to the conventional technique;

conducting solution heat treatment by heating the sheet at a heating rate of 100 °C/min or above to 450 °C or above but below 580 °C and holding the sheet in this temperature range for a period of from 10 seconds to less than 10 minutes;
cooling the sheet to 150 °C or below at a cooing rate of 100 °C/min or above;
allowing the sheet to hold still at room temperature for less than 60 minutes, and
holding the sheet at a temperature of from 50 °C to 150 °C for a period of from 10 minutes to 500 minutes.

Patentansprüche

1. Verfahren zur Herstellung eines Materials aus einer Aluminiumlegierung mit ausgezeichneter Formbarkeit, Formfixierbarkeit und Härtbarkeit durch Backen, bei dem man
halbkontinuierlich eine Legierung, die zu 0,4 bis weniger als 1,5 Gew.-% Si, 0,3 bis weniger als 0,5 Gew.-% Mg und ansonsten Al und unvermeidliche Verunreinigungen enthält, gießt, um einen Barren zu bilden,
den Barren mit einer herkömmlichen Technik zu einer endgültigen Blechdicke walzt;
eine Lösungswärmebehandlung durchführt, indem man das Blech bei einer Erhitzungsgeschwindigkeit von 100 °C/min oder mehr auf 450 °C oder mehr, aber weniger als 580 °C erhitzt und es für den Zeitraum von 10 Sekunden bis weniger als 10 Minuten in diesem Temperaturbereich hält;
das Blech mit einer Abkühlgeschwindigkeit von 100 °C/min oder mehr auf 150 °C oder weniger abkühlt;
das Blech bei Raumtemperatur für einen Zeitraum von weniger als 60 Minuten ruhen läßt und
das Blech für einen Zeitraum von 10 bis 500 Minuten auf einer Temperatur von 50 °C bis 150 °C hält.

2. Verfahren zur Herstellung eines Materials aus einer Aluminiumlegierung mit Formbarkeit, Formfixierbarkeit und Härtbarkeit durch Backen, bei dem man
halbkontinuierlich eine Legierung, die 0,4 bis weniger als 1,5 Gew.-% Si, 0,3 bis weniger als 0,5 Gew.-% Mg, außerdem mindestens eine Komponente, die aus der bis zu 0,20 Gew.-% Cu, bis zu 0,20 Gew.-% Mn und bis zu 20 Gew.-% Cr enthaltenden Gruppe ausgewählt ist, und ansonsten Al und unvermeidliche Verunreinigungen enthält, gießt, um einen Barren zu bilden;
den Barren mit einer herkömmlichen Technik zu einer endgültigen Blechdicke walzt;
eine Lösungswärmebehandlung durchführt, indem man das Blech mit einer Erhitzungsgeschwindigkeit von 100 °C/min oder mehr auf 450 °C oder mehr, aber weniger als 580 °C erhitzt und es für den Zeitraum von 10 Sekunden bis weniger als 10 Minuten in diesem Temperaturbereich hält;
das Blech mit einer Abkühlgeschwindigkeit von 100 °C/min oder mehr auf 150 °C oder weniger abkühlt;
das Blech bei Raumtemperatur für einen Zeitraum von weniger als 60 Minuten ruhen läßt und
das Blech für einen Zeitraum von 10 bis 500 Minuten auf einer Temperatur von 50 °C bis 150 °C hält.

3. Verfahren zur Herstellung eines Materials aus einer Aluminiumlegierung mit verringerter Anisotropie und ausgezeichneter Formbarkeit, Formfixierbarkeit und Härtbarkeit durch Backen, bei dem man
halbkontinuierlich eine Legierung, die zu 0,4 bis weniger als 1,5 Gew.-% Si, 0,3 bis weniger als 0,5 Gew.-% Mg, 0,02 bis 0,2 Gew.-% V und ansonsten Al und unvermeidliche Verunreinigungen enthält, gießt, um einen Barren zu bilden,
den Barren mit einer herkömmlichen Technik zu einer endgültigen Blechdicke walzt;
eine Lösungswärmebehandlung durchführt, indem man das Blech bei einer Erhitzungsgeschwindigkeit von 100 °C/min oder mehr auf 450 °C oder mehr, aber weniger als 580 °C erhitzt und es für den Zeitraum von 10 Sekunden bis weniger als 10 Minuten in diesem Temperaturbereich hält;
das Blech mit einer Abkühlgeschwindigkeit von 100 °C/min oder mehr auf 150 °C oder weniger abkühlt;
das Blech bei Raumtemperatur für einen Zeitraum von weniger als 60 Minuten ruhen läßt und
das Blech für einen Zeitraum von 10 bis 500 Minuten auf einer Temperatur von 50 °C bis 150 °C hält.

4. Verfahren zur Herstellung eines Materials aus einer Aluminiumlegierung mit verringerter Anisotropie ausgezeichneter Formbarkeit, Formfixierbarkeit und Härtbarkeit durch Backen, bei dem man
halbkontinuierlich eine Legierung, die zu 0,4 bis weniger als 1,5 Gew.-% Si, 0,3 bis weniger als 0,5 Gew.-% Mg, 0,02 bis 0,2 Gew.-% V, außerdem mindestens eine Komponente, die aus der bis zu 0,20 Gew.-% Cu, bis zu 0,20 Gew.-% Mn und bis zu 20 Gew.-% Cr enthaltenden Gruppe ausgewählt ist, und ansonsten Al und unvermeidliche Verunreinigungen enthält, gießt, um einen Barren zu bilden,
den Barren mit einer herkömmlichen Technik zu einer endgültigen Blechdicke walzt;
eine Lösungswärmebehandlung durchführt, indem man das Blech bei einer Erhitzungsgeschwindigkeit

von 100 ° C/min oder mehr auf 450 ° C oder mehr, aber weniger als 580 ° C erhitzt und es für den Zeitraum von 10 Sekunden bis weniger als 10 Minuten in diesem Temperaturbereich hält;
das Blech mit einer Abkühlgeschwindigkeit von 100 ° C/min oder mehr auf 150 ° C oder weniger abkühlt;
das Blech bei Raumtemperatur für einen Zeitraum von weniger als 60 Minuten ruhen läßt und
das Blech für einen Zeitraum von 10 bis 500 Minuten auf einer Temperatur von 50 ° C bis 150 ° C hält.

Revendications

1. Procédé pour fabriquer un matériau en alliage d'aluminium avec d'excellentes capacités de formage, de fixation de forme et de dureté par le recuit, le procédé comprenant les étapes consistant à:
- conduire une coulée semi-continue d'un alliage comprenant, en pourcentage de poids, de 0,4 % à moins de 1,5 % de Si, de 0,3 % à moins de 0,5 % de Mg, le reste étant constitué d'Al et d'impuretés inévitables pour préparer un lingot;
- laminer le lingot jusqu'à une épaisseur de feuille finale, en conformité avec la technique conventionnelle;
- conduire un traitement thermique de solution en chauffant la feuille avec une vitesse de chauffage de 100 ° C/minute ou davantage jusqu'à 450 ° C, ou davantage mais en-desous de 580 ° C, et en maintenant la feuille dans ce domaine de température pendant une durée allant de 10 secondes jusqu'à moins de 10 minutes;
- refroidir la feuille jusqu'à 150 ° C ou en-dessous, avec une vitesse de refoidissement de 100 ° C/minute ou davantage;
- laisser reposer la feuille à la température ambiante pendant une durée inférieure à 60 minutes; et
- maintenir la feuille à une température allant de 50 ° C à 150 ° C pendant une durée allant de 10 minutes jusqu'à 500 minutes.

2. Procédé pour fabriquer un matériau en alliage d'aluminium avec des capacités de formage, de fixation de forme et de dureté par le recuit, le procédé comprenant les étapes consistant à:
- conduire une coulée semi-continue d'un alliage comprenant, en pourcentage de poids, de 0,4 % à moins de 1,5 % de Si, et de 0,3 % à moins de 0,5 % de Mg, et comprenant de plus au moins un élément sélectionné à partir du groupe constitué de jusqu'à 0,20 % de Cu, jusqu'à 0,20 % de Mn et jusqu'à 0,20 % de Cr, le reste étant constitué d'Al et d'impuretés inévitables pour préparer un lingot;
- laminer le lingot jusqu'à une épaisseur de feuille finale, en conformité avec la technique conventionnelle;
- conduire un traitement thermique de solution en chauffant la feuille avec une vitesse de chauffage de 100 ° C/minute ou davantage jusqu'à 450 ° C, ou davantage mais en-desous de 580 ° C, et en maintenant la feuille dans ce domaine de température pendant une durée allant de 10 secondes jusqu'à moins de 10 minutes;
- refroidir la feuille jusqu'à 150 ° C ou en-dessous, avec une vitesse de refoidissement de 100 ° C/minute ou davantage;
- laisser reposer la feuille à la température ambiante pendant une durée inférieure à 60 minutes; et
- maintenir la feuille à une température allant de 50 ° C à 150 ° C pendant une durée allant de 10 minutes jusqu'à 500 minutes.

3. Procédé pour fabriquer un matériau en alliage d'aluminium avec moins d'anisotropie et d'excellentes capacités de formage, de fixation de forme et de dureté par le recuit, le procédé comprenant les étapes consistant à:
- conduire une coulée semi-continue d'un alliage comprenant, en pourcentage de poids, de 0,4 % à moins de 1,5 % de Si, de 0,3 % à moins de 0,5 % de Mg, et de 0,02 % à 0,2 % de V, le reste étant constitué d'Al et d'impuretés inévitables pour préparer un lingot;
- laminer le lingot jusqu'à une épaisseur de feuille finale, en conformité avec la technique conventionnelle;
- conduire un traitement thermique de solution en chauffant la feuille avec une vitesse de chauffage de 100 ° C/minute ou davantage jusqu'à 450 ° C, ou davantage mais en-desous de 580 ° C, et en maintenant la feuille dans ce domaine de température pendant une durée allant de 10 secondes jusqu'à moins de 10 minutes;
- refroidir la feuille jusqu'à 150 ° C ou en-dessous, avec une vitesse de refoidissement de 100 ° C/minute ou davantage;

- laisser reposer la feuille à la température ambiante pendant une durée inférieure à 60 minutes; et
- maintenir la feuille à une température allant de 50 °C à 150 °C pendant une durée allant de 10 minutes jusqu'à 500 minutes.

4. Procédé pour fabriquer un matériau en alliage d'aluminium avec moins d'anisotropie et d'excellentes capacités de formage, de fixation de forme et de dureté par le recuit, le procédé comprenant les étapes consistant à:
- conduire une coulée semi-continue d'un alliage comprenant, en pourcentage de poids, de 0,4 % à moins de 1,5 % de Si, de 0,3 % à moins de 0,5 % de Mg, et de 0,02 % à 0,2 % de V, et comprenant de plus au moins un élément sélectionné à partir du groupe constitué de jusqu'à 0,20 % de Cu, jusqu'à 0,20 % de Mn et jusqu'à 0,20 % de Cr, le reste étant constitué d'Al et d'impuretés inévitables pour préparer un lingot;
- laminer le lingot jusqu'à une épaisseur de feuille finale, en conformité avec la technique conventionnelle;
- conduire un traitement thermique de solution en chauffant la feuille avec une vitesse de chauffage de 100 °C/minute ou davantage jusqu'à 450 °C, ou davantage mais en-desous de 580 °C, et en maintenant la feuille dans ce domaine de température pendant une durée allant de 10 secondes jusqu'à moins de 10 minutes;
- refroidir la feuille jusqu'à 150 °C ou en-dessous, avec une vitesse de refroidissement de 100 °C/minute ou davantage;
- laisser reposer la feuille à la température ambiante pendant moins de 60 minutes; et
- maintenir la feuille à une température allant de 50 °C à 150 °C pendant une durée allant de 10 minutes jusqu'à 500 minutes.