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ALUMINUM ALLOYS--INDUSTRIAL
DEFORMABLE, SINTERED AND LIGHT
ALUMINUM ALLOYS

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The author discusses the hardening and characteristics of
alloys from various multicomponent systems, including binary,
ternary and quaternary alloys, their advantages and use.
A new standard alphanumerical system for designating various
alloys is described.

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INTRODUCTION[1]

The composition of industrial aluminum alloys and the structure and properties of the products manufactured from them are determined, to a considerable extent, by the production method used. Aluminum alloys can be classified into two main groups by the production method used: deformable alloys used for the manufacture of various semi-finished products under pressure treatment (machines, slabs, bars, sections, pipes, stamped products, and wires) and cast alloys for the production of shaped castings.

The billets that are mainly used for the subsequent deformation of the aluminum alloys are ingots, but for sintered alloys, powder cake. In small volumes, the shaped parts are obtained directly from the powders. Foam aluminum is manufactured on a small scale by decomposing in liquid aluminum titanium or zirconium hydrates or by other methods.

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Depending on the purpose for which they are intended and the requirements on the mechanical, corrosive, technological, physical and other properties, aluminum alloys are classified into high strength, medium strength and low strength alloys, refractory alloys, cryogenic alloys, forging alloys, rivetted alloys, welded alloys, alloys with special physical properties and decorative alloys. Usually aluminum alloys are prepared from primary aluminum to which considerable amounts of high grade waste materials are added. Special secondary aluminum alloys exist, in whose preparation low grade waste materials are used with a high admixture content (secondary aluminum alloys). A part of the lowest grade aluminum alloys is used for reduction in ferrous metallurgy.

Hardening of deformable aluminum alloys and also a change in the physical, corrosive and technological processes are obtained with the aid of various methods: cold hardening, thermal treatment (tempering, aging), tempering from the liquid state, thermomechanical treatment, hardening with insoluble phases, hardening with insoluble admixtures of sintered aluminum powder (SAP) and composite materials with an aluminum matrix.

The term "tempering from the liquid state" was proposed in 1948. Tempering from the liquid state consists of the rapid cooling of alloys from the liquid state, as a result of which solid solutions are obtained which are oversaturated

from the standpoint of maximum possible equilibrium solubility in the solid state.

Cold hardening (which increases the strength and the yield point) is particularly suitable for alloys which cannot be hardened by thermal treatment. However, cold hardening is used for products whose shape is simple (sheets, plates) and also hardening obtained by means of cold working is eliminated in the welding zone.

Thermal treatment (tempering and aging) of aluminum alloys in the solid state is most important. The discovery of the hardening effects in new systems (Table 1) makes it possible to manufacture new alloys with properties that were unknown so far. The hardening effects were discovered relatively recently in the systems Al-Cu-Mn (D20 type alloy base), Al-Cu-Li and Al-Li-Mg.

Magnalium (Al-Mg alloys) are typical representatives of aluminum alloys which are hardened as a result of the formation of oversaturated solid solutions.

Magnalium, like all alloys of the solid solution type (equilibrium or oversaturated alloys), is characterized by high plasticity (δ = 15-20%) resistance to corrosion, a relatively low shearing strength (at 5-6% Mg $\sigma_{B\ max}$ = 34 - 36 kg/mm^2) and yield point ($\sigma_{0,2\ max}$ = 20 - 24 kg/mm^2)

and reduced sensitivity to concentrated stresses. Many

alloys in the system are easily welded using electric arc

welding with a slight reduction in the strength in the welding

zone, and they can be polished well.

TABLE 1. MAIN SYSTEMS OF ALUMINUM ALLOYS HARDENED BY THERMAL TREATMENT

a Система	b Фазы, вызывающие эффект термической обработки	c Метастабильные зоны и фазы, возникающие в процессе термической обработки	d Год открытия упрочняющего эффекта	e Авторы
Al—Mg—Si	β (Mg$_2$Si)	ГП; β'	1915—1921	Гейлер
Al—Cu—Mg	θ (CuAl$_2$) S (Al$_2$CuMg)	ГП; $0''$, $0'$ ГПБ; S$''$, S$'$	1909—1911	Вильм
Al—Zn—Mg	η (MgZn$_2$) T (Al$_2$Mg$_3$Zn$_3$)	Зоны; η'	1923—1924	Зандер, Мейснер
Al—Zn—Mg—Cu	η (MgZn$_2$) T (Al$_2$Mg$_3$Zn$_3$)	Зоны; η'	1932	Вебер
Al—Cu—Mn	0 (CuAl$_2$) (Al$_2$Mn$_2$Cu)	ГП; $0''$; $0'$	1938 1950	Петри Фрагмен
Al—Cu—Li	0 (CuAl$_2$), (Al$_{7,5}$Cu$_4$Li), T (Al$_2$CuLi)	$0'$; T	1956	Харди, Силкок
Al—Li—Mg	S (Al$_2$LiMg), δ (AlLi)	δ' (Al$_3$Li)	1963—1965	Фридляндер И. Н., Шамрай В. Ф., Ширяева Н. В.

Key: a. System
   b. Phases, causing thermal treatment effect
   c. Metastable zones and phases formed in the thermal treatment process
   d. Year in which hardening effect was discovered
   e. Authors

Key, Table 1 (continued):

Column c:

1. GP
2. SPB
3. Zones

Column e:

Heiler

Wilm

Zander,
Meisner

Weber

Petri
Fragman

Hardy
Silcock

Fridlyander, I. N..,
Shamray, V. F.,
Shiryayeva, N. V.

Magnalium is widely used in various structures including welded structures which require high resistance to corrosion-- in river and sea ships, pipelines, hydroaviation, rocket fuel tanks, bridges, cisterns, railroad cars, buildings, window frames, doors, decorative articles, and in the cooling elements of household refrigerators.

At high temperatures and liquid hydrogen temperatures, the use of magnalium is not justified.

The strength characteristics of alloys can be increased 10-40% by cold working when necessary, with subsequent

tempering to improve the plasticity and corrosion resistance. Cold hardened sheets made from the AMg6 and AMg61 alloys have $\sigma_B \approx 40$ kg/mm^2, $\sigma_{0,2} \approx 30$ kg/mm^2, $\delta \approx 100\%$ and the welded joints of cold-hardened and annealed alloys have practically the same strength.

The formation of oversaturated solid solutions from the liquid state is characteristic of aluminum alloys marked by their low solubility in the solid state and a sharply increasing liquidus curve (Al-Mn, Al-Cr, Al-Zr, and others). Although these alloys are characterized by their low strength ($\sigma_B \approx 20$ kg/mm^2 for the AMn alloy), they have certain important physical characteristics (for example, the AMn1 alloy with 2 - 4.5% Mn has a small electric resistance temperature coefficient which is less than $0.7 \cdot 10^{-3}$ in the temperature range 0 to 100°C). The decomposition of the manganese, chromium, zirconium in the aluminum which was formed as a result of the hardening of the oversaturated hard solution from the liquid state, already begins at temperatures 200-400°C.

Many aluminum alloys are strengthened by thermal treatment, hardening with subsequent tempering (natural or artificial-- zonal or phase aging).

The content of the main alloying elements in the deformable aluminum alloys that are hardened by thermal treatment usually does not exceed their solubility in aluminum. In

addition to the principal elements, certain small admixtures
are introduced into the alloys, which have a considerable
effect on the decay kinetics of the oversaturated solution,
the recrystallization process, the corrosion and technological
properties, the weldability and the grain size. Among these,
some of the most important admixtures are chromium, manganese,
and vanadium, which can form with the aluminum solid
solutions oversaturated from the liquid state, berrylium,
which reduces the oxidability of the alloys, and certain rare
earth elements.

The concentration and ratio of the iron and silicon
admixtures that are constantly present in the aluminum,
have a great effect on certain technological, especially
casting properties, in particular the tendency to form
crystallization cracks and also on plasticity.

The plasticity of the metal can be considerably increased
by reducing the amount of iron and silicon   admixtures in the
Al-Zn-Mg-Cu alloy systems By reducing the silicon content in
the B93 alloy, it was possible to increase from 1.5 to 4-5%
the relative elongation of the samples cut out along the
thickness from massive pressed pieces.

In all cases, hardening by thermal treatment is
possible due to the existence in the system of one or several

chemical bonds which are soluble in the aluminum, whose solubility is reduced with the drop in the temperature. The greatest thermal treatment effect results from bonds formed by at least two elements in addition to the aluminum. In each system, there are usually several industrial alloys which differ considerably from one another by their properties but also have important common features that are characteristic of all the alloys in one system.

Alloys from the Al-Cu-Mg system (duraluminums) are characterized by a mean strength on the order of 42-46 kg/mm^2, $\sigma_{0,2}$ = 28-30 kg/mm^2, δ = 15-17%. They are mainly used in structures joined by rivets, bolts, and by welding, even though alloys from the Al-Cu-Mg system have been developed that are welded using electric arc welding (VAD1, M40). Alloys on the duraluminum type, including the most important ones, D1 and D16, are relatively insensitive to the action of repeated static and vibration loads, they do not tend to corrode under a load but they do have a lower total resistance to corrosion. The D16 alloy is used on a wide scale on surface areas in aircraft and drill pipes in oil wells. The D1 alloy is used for propeller blades. When the working temperature is increased, the resistance to corrosion of the D1 and D16 alloys is reduced and they become brittle. Depending on the time they are used, these phenomena occur for the D16 alloy at 80-90 (after several tens of thousands of hours) to 150°C (after 10 hrs.).

The parts made from the AK4-1 alloy which are subjected to prolonged heating yield much better results at higher temperatures in reactive force engines in supersonic aircraft. Unlike the D16 alloy, the AK4-1 alloy does not contain manganese, but insoluble iron and nickel admixtures (each 1.1%) and the lead concentration is reduced two times as much.

Alloys from the Al-Mg-Si system (AD31, AD33, AV) have a lower strength (32-34 kg/mm^2, they are highly resistant to corrosion and highly plastic (when these alloys are pressed, high rates are attained), they are highly resistant to fatigue, including corrosion fatigue, have good polishing characteristics and a beautiful decorative appearance. Helicopter blades, window frames, panels of buildings are manufactured from the Al-Mg-Si and they are also used in the manufacture of watch casings and jewelery in a gold or other color. These types of alloys are distinguished by the advantageous combination of a comparatively low electrical resistance and sufficiently high strength, and they are used on a wide scale in electric wires, coils in electric-driven motors and for other electrical engineering purposes.

The alloys from the Al-Mg-Si-Cu system (AK6 and AK8) are characterized by their good casting properties, which make it possible to cast casts with any diameters that are needed (1200-1400 mm) and by their high plasticity in the hot state. They are widely used in the manufacture of forgings and pressed

pieces, including large pieces with complex shapes. In
recent years, the AK6 and AK8 alloys have been replaced by
the stronger forging alloys from the Al-Zn-Mg-Cu system
which are used for operations at room temperatures. The
AK8 alloy works satisfactorily in welded structures at liquid
hydrogen temperatures, but better results are obtained with
the D20 alloy (Al-Cu-Mn).

The Al-Zn-Mg alloys may have high strength, σ_B up
to 45-50 kg/mm^2, $\sigma_{0,2}$ = 35-45 kg/mm^2. They are efficient and
welded sufficiently well using electric arc welding and the
seam zone is only slightly weakened. However, the alloys
are more sensitive to corrosion under stress and to slow
fracture (in spite of the high total corrosion resistance).
The tendency to corrode under stress is larger the higher
the zinc and magnesium concentration and, hence, the higher
the strength. At the present time alloys are being prepared
with strength not exceeding 30-40 kg/mm^2 for welded structures,
including those structures used at cryogenic temperatures.

The introduction of copper in the Al-Zn-Mg alloys (along
with small admixtures--stabilizers, Cr, Mn, Zr) made
it possible to considerably improve their resistance to
corrosion under stress while retaining the high strength (for the
B95 alloy σ_B ≈ 55-60 kg/mm^2, for the B96 alloy σ_B ≈ 70 kg/mm^2).
These alloys are widely used in compressed structural zones

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operating at a temperature up to 100°C (at a higher tempera-
ture, they are weakened). The forging B93 alloy
($\sigma_B \approx 50$ kg/mm^2) does not have chromium, manganese and zir-
conium admixtures, which improves its technological properties.
The largest forgings and stamped pieces in the world are
made from the B93 alloy, they have the same strength
($\sigma_B \approx 48$ kg/mm^2) in any direction and in any cross section
(up to 1 m thick), and they are hardened in hot water, which
reduces the buckling. The high-strength Al-Zn-Mg-Cu alloys
are sensitive to concentrated stresses and corrosion under
stress. At the present time, high-strength weldable alloys
from the Al-Zn-Mg-Cu system are being developed.

The Al-Cu-Mn alloys (D20 and others) have medium strength
($\sigma_B \approx 40$ kg/mm^2), but they are hardened between the tempering
and aging by cold working ($\sigma_B \approx 40$-48 kg/mm^2). The alloys
are characterized by their comparatively high resistance to
heat at 200-250°C and they are used on a wide scale in welded
structures at liquid hydrogen temperatures. The strength of
the welded seam is substantially below the strength of the
basic material. The total resistance to corrosion is con-
siderably lower in these alloys, especially in the welded
seam zone, but they have satisfactory corrosion resistance
under stress.

The Al-Cu-Li alloy (VAD23) is distinguished by its high strength ($\sigma_B \approx$ 50-60 kg/mm^2) which depends on the aging and resistance to heat; it is 3% lighter than the AK4-1 alloy and 6% lighter than the B95 alloy. It is less sensitive to the action of repeated static loads than the B95 alloy. Its modulus of elasticity is 5% higher than that of the other alloys. With respect to corrosion resistance, it comes close to the D16 alloy. However, its use is very limited.

The Al-Li-Mg alloy (01420) comes close by its strength characteristics to the D16 alloy but it differs from it by its high resistance to corrosion. The 01420 alloy is 11% lighter than the D16 alloy and it has a larger modulus of elasticity (8% larger).

Aluminum alloys with lithium are characterized by the deviation from the additivity rule in the modulus of elasticity ratio E, in spite of the low modulus of elasticity of the lithium.

In aluminum alloys with lithium the elasticity modulus is higher.

All aluminum alloys hardened by thermal treatment obey general laws for the change in the structure of the decomposition of the oversaturated solid solution and the associated properties. The Hinier-Preston zones are formed at a certain aging stage (for the Al-Cu-Mg alloys, the Hinier-Preston-Bagaryatskiy zones). This stage can be characterized

as the zonal aging stage. When the aging temperature is raised (or the duration of the aging is changed when the temperature is sufficiently high), metastable phase particles are formed (possibly several metastable modifications) which corresponds to the phase-aging stage. After this, larger metastable phase particles appear (the coagulation stage begins during the aging), and, finally, the stable phase particles are formed which become larger (annealing).

The transition from zonal to phase aging and coagulation requires a certain time during the aging, which is longer the lower the aging temperature. The transition is gradual, due to the chemical and structural inhomogeneity of the alloy, and it is characterized by the segregation, the presence of grain and subgrain boundaries, the different dislocation density, the microstresses formed by the joint presence of zones and metastable particles and then stable phases.

A particular set of properties characterizes each aging stage regardless of the system of aluminum alloys. In the case of zonal aging, the maximum strength characteristics are not attained no matter how long the aging, since the alloys are not weakened in the process. Zonal aging is characterized by the relatively low yield point (the ratio $\sigma_{0,2}/\sigma_B = 0.6 - 0.7$), the high elongation ($> 10 - 15\%$), the electrical resistance which increases during the aging, the high resistance to corrosion, including corrosion resistance

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under stress, the high impact viscosity, and the low
sensitivity to a crack. The high relative elongation of
zone-aged alloys and the low yield point are due to the
high uniform elongation, since the dislocations intersect
zones that do not display high resistance to the initial
deformation. The resistance to corrosion of the alloys
is raised due to the absence of separation boundaries between
the zones and the matrix.

The phase aging is characterized by the high yield point
($\sigma_{0,2}/\sigma_B$ > 0.9 - 0.95), the low elongation, the reduced im-
pact viscosity, the resitance to the development of cracks,
and the resistance to corrosion under stress. The maximum
yield point during isothermic aging occurs later than the
maximum strength limit. The low elongations of the alloys
in the phase aging stage are due to the sharply reduced
uniform elongation. The metastable phase dislocation
particles that appear in the structure bend them. forming
many dislocation loops, as a result the resistance to the
initial deformation increases sharply, the yield point attains
higher values and the uniform elongation is reduced. The reduced
resistance to corrosion is caused by the separation boundary
which appears between the metastable phase particles and
the matrix.   The tendency to corrode under stress may be
especially increased when the metastable phase particles
form a continuous chain along the grain boundaries that make

contact with the zone in which there are no precipitations
and with the impoverished zone.

During coagulation in the aging process, the strength
and yield point having passed the maximum are reduced, the
elongation, the impact viscosity, and the resistance to
the development of cracks are somewhat increased and the
resistance to corrosion under stress and to slow fracture is
considerably improved (a possible reason for this improvement
may be the larger metastable phase particles, the disturbed
continuity of the precipitation change, the formation of
clearances between the particles and the reduced dislocation
density as a result of their annihilation). For some alloys,
the substantial improvement in their resistance to corrosion
during isothermic aging coincides with the maximum yield point.
In practice, a number of important characteristics depends
little on the aging stage. These include the local elongation
in the seam zone, the narrowing of the cross-section, the
resistance to fatigue, the long-term strength and creep.
Apparently, during the tests themselves, the zone-aged alloys
make the transition to the phase aging stage.

Each aged aluminum alloy has its own temperature-time
regions for the zone and phase aging.

For the Al-Cu-Mg, Al-Mg-Si, Al-Cu-Mg-Si and Al-Zn-Mn-Cu
alloy systems, the zone aging occurs at room temperature, even
though the boundary of this aging stage is shifted towards the

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higher temperatures; for the Al-Zn-Mg alloy systems, the
zone aging makes the transition to the phase aging at room
temperature.   The Al-Cu-Mn, Al-Cu-Li, Al-Mg-Li alloy systems
do not age at room temperature for all practical purposes,
they must be heated to realize the zone aging. Therefore,
the terms "natural aging" and "artificial aging" must only
be used to designate the aging conditions, i.e., without
heating or with heating and to characterize the structural
state and the corresponding set of properties, the terms
"zone aging" and "phase aging" and "coagulation during aging"
must be used. Hence, there may be natural zone aging
and artifical zone aging regimes and also the corresponding
natural phase aging and artificial phase aging. Thus, for
example, the aging of the AK6 alloy in the lower standard
regime boundaries corresponds to artificial zone aging and
the upper standard regime boundaries to artificial phase
aging. Prolonged (2-3 years) natural aging of the B92
alloy or other strong alloys from the Al-Zn-Mg system re-
presents natural phase aging and natural zone aging corres-
ponds to a shorter time period.

Mechanical-thermal treatment is important for various
aluminum alloys. The special deformation conditions (for
example, a sufficiently high temperature) either retain in
the aluminum the oversaturated solid solution of manganese,

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chromium and other similar transition elements, or bring about a favorable dispersion and distribution of the decomposition products of this solution during the deformation and the subsequent heating for the tempering.

Because of this, considerable differences occur in the properties of hot and cold-deformed semi-finished products made from aluminum alloys. Hot-deformed semi-finished products have higher strength characteristics and a higher creep limit, and considerably higher resistance to corrosion under stess, which is extremely important in practice (the so-called press-effect and forging effect). It should be mentioned that usually hot deformation leads to an uncrystallized structure with smaller dislocation density and other structural defects, a lower degree of decomposition of the solid chromium manganese and zirconium solution supersaturated from the liquid state in the aluminum. In the case of cold-rolled sheets from the AK4-1 alloy, the creep limit may be increased by changing the rolling technology, as a result of which larger grains and subgrains are formed.

The greatest strengthening effect in aluminum (up to 80 kg/mm^2) and some other important physical characteristics are obtained with the aid of insoluble admixtures, metallo-ceramically. At the present time, two groups of metallo-ceramic and aluminum alloys that are important in industry exist:

SAP (sintered aluminum powder) and SAA-1 (sintered aluminum alloy). The SAP is hardened with dispersed alumina particles which are insoluble in aluminum. The oxygen is introduced into the aluminum by forming a very thin film on the particles of the highly dispersed aluminum powder when it is ground in spherical mills in a nitrogen atmosphere in which the oxygen content is regulated. Stearine is added during the grinding. As it is vaporized, along with the crushing of the original powder, the particles merge and form larger conglomerates, as a result of which the so-called heavy powder with density $> 1.0 \text{ g/cm}^3$ is formed which is not inflamable in air. The powder is caked, sintered, and subjected to further deformation, pressing, rolling, and forging. The strength of a sintered aluminum alloy increases as the original alumina content increases (formed on the original particles) to 20-22%, and drops subsequently. The strength limit of sintered aluminum powder is approximately inversely proportional to the distance between the alumina particles (quantitatively, this relationship must still be put on a solid static basis).

The structure of SAP consists of the cold hardened aluminum matrix with a cellular structure strengthened by the insoluble dispersed alumina particles. Fine grinding of the original powder provides the dispersion of the oxide films and particles.

The hardening laws for the sintered aluminum powder are no longer valid when the oxide films are coarser. From the four grades of sintered aluminum powders which differ in their alumina content (SAP-1 $\approx$ 8% Al_2O_3, SAP-4 $\approx$ 20% Al_2O_3), SAP-1 and SAP-2 with strength on the order $\sigma_B \approx$ 33 kg/mm^2, $\sigma_{0,2} \approx$ 23 kg/mm^2, $\delta \approx$ 8% are most widely used. As the temperature increases, the strength limit of SAP, unlike the σ_B of thermally treated aluminum alloys, varies along a straight line whereas the strength limit of pure aluminum and its alloys with magnesium drops approximately to zero. However, even above this temperature, the SAP retains a certain strength as a result of the surface tension and the strength of the oxide film. Holding the SAP for a long time below the aluminum melting temperature has little effect on its strength. Above 200-250°C, especially when it is held at these temperatures for a long time, the strength of SAP is higher than that of all other aluminum alloys. At 500°C, $\sigma_B \approx$ 5-8 kg/mm^2. SAP is used in the shape of sheets, sections, forgings, pressed pieces, wherever high heat resistance and resistance to corrosion are needed.

Similarly, as thermally treated aluminum alloys in the phase aging stage, the hardening of SAP is explained by the resistance of the dispersed alumina particles to dislocation movements which bend the particles and form around

dislocation loops. Because of the absence of a diffusion interaction between the matrix and the alumina particles, their shapes and dimensions remain unchanged during the heating providing the high heat resistance of the SAP. In aging aluminum alloys, because of the coagulation of the metastable phase particles and their conversion into stable phase particles, their strength is higher than in SAP, and it drops sharply at comparatively low temperatures during increased heating.

The SAP lave a very high moisture content which is adsorbed and maintained stable by the oxidized surface of the powders and the cold-pressed cake. Well degassified SAP have greater plasticity and are well welded using electric arc welding.

The sintered aluminum alloy with 25% Si and 5% Ni (or Fe) content has a smaller linear expansion coefficient and a higher modulus of elasticity E. The SAA-1 alloy is obtained by pulverizing the liquid alloys, by caking the pulverizer and by pressing of bars and their forging. The small Si and $FeAl_3$ ($FeNi_3$) crystals strengthen the alloy, raise the E and the plasticity, and reduce the linear expansion coefficient. Their effect is greater the smaller the hard particles and the smaller the clearances between them. In these characteristics the powder alloys considerably excel the corresponding cast

aluminum alloys. Various methods of hardening aluminum can be combined, for example, tempering of alloys from the liquid state with zirconium, manganese and titanium and introducing into the matrix aluminum particles of the SAP type. Another hardening variant is combining the powder aluminum in the $Al-Cu-Mg-Al_2O_3$ system with the effect of the hardening phases that are soluble in the solid state. At comparatively low temperatures, the metastable modification of the $S(Al_2CuMg)$ phase enhances the high strength of the alloy. At the highest temperatures, the Al_2O_3 phase provides high heat resistance.

Alloys from the Al-Be-Mg system are among the alloys that are hardened by insoluble phases along with soluble phases. These alloys are among highly eutectic ones, structurally they are a matrix in the form of a solid solution of manganese in aluminum and particles of practically pure berrylium.

Binary Al-Be alloys are characterized by the great difference in the properties determined by the structure of soft aluminum and brittle hard berrylium. During the alloying of alloys from the Al-Be system, additives are selected which only interact with the aluminum phase. Manganese, which is insoluble in berrylium but strengthens the aluminum is suitable for this purpose. The strength, plasticity and modulus of elasticity of the alloys are increased.

A. A. Bochvar has shown that the most important casting properties of alloys (fluidity, the volume of the internal vacancies, the resistance to residual stresses, etc.) are substantially improved in the presence of a sufficient amount of the eutectic in the alloy. Usually cast aluminum alloys contain a higher concentration of alloying elements than deformable aluminum alloys.

Cast aluminum alloys, like deformable alloys, can be classified into five groups:

1. Alloys with a high Si content (higher than 5%)--the silumins. This group includes the binary alloys Al-Si (AL2), the ternary alloys Al-Si-Mg(AL9), Al-Si-Cu(AL6), the quaternary alloys Al-Si-Mg-Cu (AL5-AL10, AL13); and to alloys from the Al-Si-Mg and Al-Si-Mg-Cu systems it is customary to add manganese (to the AL4 and AL3 alloys, respectively). Alloys in this group are characterized by good casting proper-ties, comparatively high resistance to corrosion, medium strength, and they are used for complex castings. To improve their properties, they are subjected to modification which leads to a fractionation of the brittle silicon phases, and sodium in a 0.05-0.08% concentration is used as the modifier which is introduced into the melted metal in the form of a mixture of haloid sodium and potassium salts, sometimes in the form of metallic sodium. Silumins with a high silicon content are modified with red phosphorus. The

modification is usually carried out at a higher temperature and it saturates the metal with hydrogen and other non-metallic impurities. To purify the metal, it is necessary to keep it, after it was treated and before it is cast, in a vacuum or use a universal flux having a modifying action.

2. Alloys with a high manganese content (higher than 5%), binary Al-Mg(AL8) alloys, alloys in the Al-Mg-Si system with manganese additives (AL13) and with a berrylium and titanium additive (AL22). Alloys in the second group are corrosion resistant, have high strength and lower specific gravity. The AL8 alloy has the highest strength, but it is handled with difficulty in manufacturing.

To reduce the oxidation in the liquid state, 0.05-0.07% Be is introduced into it in the liquid state to reduce the size of the grain, the same amount of titanium is introduced into the molding mixture, and to suppress the reaction of the metal with the moisture, boric acid is added. The AL8 alloy is mainly cast in sand moulds and strengthen with the aid of tempering.

The AL13 alloy has better casting properties but lower strength, it is not subjected to thermic treatment, it is cast in an iron mould and also in sand under pressure.

Protracted low-temperature heating may lead to a deterioration in the corrosion resistance of cast aluminum alloys with a high manganese content.

3. Alloys with a high zinc content (greater than 3%) from the Al-Si-Zn (AL11) and Al-Zn-Mg-Cu(B15) systems have higher specific gravity and lower corrosion resistance. They are distinguished by good casting properties and they can also be used without thermal treatment. However, these alloys are not used on a wide scale.

4. Alloys with a high copper content (higher than 4%)-- binary Al-Cu alloys (AL7 and AL12 alloys) and the alloy with the titanium additive from the Al-Cu-Mn system (AL19). These alloys have a lower corrosion resistance and casting properties, lower tightness, but with respect to refractory properties, they are better than the alloys in the first three groups.

5. Alloys from the Al-Cu-Mg and Al-Cu-Mg-Si system with manganese and iron additives (AL1, AL22, AL21) are character- ized by their high resistance to heat and poor manufacturing engineering properties.

Depending on the casting method, the properties of the alloys vary considerably, they are better the greater the crystallization rate and the supply of the crystallizing layer. Usually, the highest characteristics are attained during iron mould casting. The properties of separately cast samples may exceed the properties of the more slowly crystallized samples or poorly fed parts of the cast by a factor of two. Some elements have an advantageous effect

on certain alloys but a disadvantageous effect on other alloys. Silicon reduces the strength of Al-Mg alloys. The addition of zinc worsens the mechanical properties of alloys from the Al-Si and Al-Cu systems. Tin and lead, even in several tens of a fraction of a percent, already considerably reduce the initial melting temperature of alloys. Iron which brings about the formation of a brittle eutectic Al-Si-Fe, which crystallizes in the form of plates has a harmful effect on silumins . The regulation of the iron content depends on the casting method, it is maximal during casting under pressure and in an iron mould and much lower during casting in sand.

By reducing in the alloys the harmful metallic and non-metallic admixtures as a result of using a pure mixture and refining, introducing small titanium-zirconium and berrylium additives, alloy modification and thermal treatment, the characteristics of moulded aluminum alloys can be considerably imp oved. The refining is carried out using various methods --gas blowing (using chlorine, nitrogen, argon) the action of fluxes containing chloride and fluoric salts, holding in vacuum, or a combination of these methods.

Numerical Designation of Aluminum Alloys

At the present time a mixed alphabetical and alphabetical-digital designation is used for aluminum alloys (for example,

an aluminum and manganese alloy is designated as AM, an
aluminum-mangangese-silicon-copper alloy the so-called
Avial alloy by AV, duralumins   by D16, D1, etc.). The
use of letters and digits is by and large arbitrary
although there are some exceptions. In the AM alloy that
was already mentioned, the letter M is the symbol for manganese,
alloys of the manganese types are designated by AM (aluminum-
manganese) and the digits which follow the letters AM-1
AM-6 correspond more or less to the manganese content in
these alloys. For a group of alloys, the first digits 1,
2, 3 and 9 after the letters designate respectively: 1--
alloys hardened by copper and manganese (D16), 2--alloys
hardened by copper and manganese or copper, lithium, manganese,
cadmium (D20), 3--alloys hardened with manganese and silicon
(AD31), 9--alloys hardened with zinc and manganese or zinc
manganese and copper (B95), etc. The designation of some
forging alloys has the letters AK (AF) (aluminum forging)
alloys, AK6, AK8 and AK4-1, etc.

Metalloceramic aluminum alloys with aluminum oxide are
called SAP (sintered aluminum powder). The same alloys with
other additives besides aluminum oxide alloying
elements are called SAS (SAA) (sintered aluminum alloys).
Aluminum specially saturated with hydrogen bubbles is called
foam aluminum. In addition to not being systematic, the
mixed letter and letter-digit designation is not suitable for

taking into account the mechanical properties. Therefore, it is useful to switch to a standard digital designation of aluminum alloys. As a result of lengthy discussions and deliberations, a designation was developed which is gradually being incorporated in practice. Basically a system consisting of four digits is used for the designations. The first digit--1--denotes the base of all aluminum alloys. The next digit characterizes the main alloying component or a group of main alloying components. In a number of cases an attempt has been made to group the alloys by the principle of hardening phases. All aluminum alloys can be classified into ten groups; for the time being seven digits are used and three digits, 6, 7 and 8, are left as reserve digits. The last two digits characterize the number of the alloy. Thus each group can include up to 100 alloys, which is fully satisfactory. The total sum of all alloys can be 1000.

At the present time the number of all engineering and experimental alloys does not exceed 100-150. The last digit must satisfy an additional constrain--all deformable aluminum alloys are designated by odd numbers (including zero). The metalloceramic method is characterized by the last digit, 9, and all cast alloys have even last digits. Whenever possible, the existing numerical designation is tied in with the new designation. Experimental alloys are

designated by 0, which precedes the digit 1. Thus, experimental alloys which are an exception have a five digit designation. An experimental alloy may be in the testing and experimental stage no more than 3-5 years, after which the zero is removed and the alloy becomes a serially produced alloy, when it has proved itself or if it is no longer used when it turned out to be unsatisfactory.

The following classification of aluminum alloys by main groups is proposed.

The second digit (0) denotes pure aluminum grades. Since there are only a few of these, this group also includes SAP hardened by aluminum oxide and foam aluminum. All numbers from 1000 to 1018 are reserved for pure aluminum; all numbers ending in the digit 9, i.e., 1019, 1029, 1039, 1059, 1069, 1079, 1089, 1099, are used for designating SAP and the numbers from 1020 to 1025 are used to designate foam-aluminum grades.

The group in which the second digit is 1 includes the alloys from the Al-Cu-Mg, Al-Cu-Mg-Fe-Ni systems, namely: 1100-D1, 1160-D16, 1161-D6, 1190-D19; 01191-VAD1, 1190-VD17, 01171-M40, 1180-D18, 1165-V65, 1120-AK2, 1140-AK4, 1141-AK4-1.

The group in which the second digit is 2 includes alloys from the Al-Cu-Mn and Al-Cu-Li-Mn-Cd systems, namely, 1200-D20, 1210-D21, 01230-VAD-23.

The group of alloys in which the second digit is 3 includes the systems Al-Si, Al-Mg-Si and Al-Mg-Si-Cu, namely, 1310-AD31, 1330-AD33, 1350-AD35, 1340-AV (without copper), 1341-AV (with copper), 1360-AK6, 1380-AK8, 01319-SAS-1.

The second digit 4 is associated with alloys whose main alloying elements are components that are insoluble or slightly soluble in aluminum, in particular, Al-Mn, Al-Cr, Al-Be, namely, 1400-AM, 1401, AM-1, 1439-aluminum + chromium, 1411-ABM-1.

The group of alloys in which the second digit is 5 includes alloys of the magnalium type, namely, 1511-D12, 1510-AMg1, 1520-AMg2, 1530-AMg3, 1540-AMg4, 1550-AMg5, 1560-AMg6, 1561-AMg61

The group of alloys in which the second digit is 9 are alloys from the systems Al-Zn-Mg and Al-Zn-Mg-Cu, namely: weldable medium strength alloys with zinc and magnesium, 01920-V92, 1930-V93, 1940-V94, 1950-V95, 1960-V96, 1969-V96-SAS, 01980-V48-4.

Designation for Different Types of Thermal Treatment

The state of semi-finished products made from deformable aluminum alloys is designated by letters and digits: M--soft and annealed, T--tempered and aged naturally, T1--tempered and aged artificially, N--cold hardened, P--semi-cold hardened (the letter "P" which is a part of the designation for the

alloy indicates that the alloy is a wire alloy),
N1--intensely cold hardened alloy (the cold-hardening of the
sheets is approximately 20%), TN--hardened, naturally aged
and cold-hardened alloy, T1N--hardened, cold worked and ar-
tificially aged alloy, T1N1--hardened, cold worked, 15-20%
and artificially hardened alloy.

The conventional designation for the different types
of thermal treatment of cast alloys are as follows: T1--aging,
T2--annealing, T4--tempering, T5--tempering and partial aging,
T6--tempering and full aging to maximum strength, T7--tempering
and stabilizing tempering. T8--tempering and softening tem-
pering. For the casting method the letters "Z" (S) in
sand (ground), "O" (S) in shell moulds, "V" (M) by melted
models, "K" (I) in iron mould, "D" (P) under pressure. The
letter "M" denotes that the alloy was modified during the
casting.