SOLUTION TREATMENT OF ALUMINUM ALLOYS IN THE AERODYNAMIC HEATING FURNACES

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ABSTRACT

AHTF furnaces, in which air or gas is heated to 600-700^{o}C without electrical or other special heaters, have been developed and placed in operation in a number of plants for heat treating aluminum, magnesium, and titanium alloys, and also steels. The AHTF chamber furnace is thermally insulated without the use of fire bricks. It has a centrifugal fan with vanes having a special contour. The fan, operating in a closed system, converts, into heat, almost all the energy used to turn it; the heat is transferred to the parts by convection. In most machine building plants aluminum alloys are heat treated in ERF furnaces (electric resistance furnaces with forced air circulation) or in salt baths. This research deals with an investigation of the heating conditions for various semifinished products of aluminum alloys in the AHTF-3 in comparison with the ERF-2 furnace and a potassium nitrate bath of approximately the same working volume.

THE AHTF FURNACE

The invention of aerodynamic heating process in the former Soviet Union in 1963-1964 resulted in the introduction of a new class of industrial heating devices. The principle of aerodynamic heating is a transfer of gas flow energy generated by a centrifugal fan into heat. The rotor of the centrifugal fan serves as a compressor, and as a heat generator. It induces circulation in the furnace atmosphere and generates heat at the same time. The first industrial furnaces were developed by a design team headed by Dr. P. I. Tevis[6] and others [1-4].

There is no uniform, widely accepted terminology on the subject. For practical applications the most widespread term is “aerodynamic heat treat furnace (AHTF),” or “aerodynamic loss furnace.” We must emphasize the difference between the meaning of the term “aerodynamic heating” in our case, and its usage in the aerodynamics of hypersonic flows. In the latter instance, this term is used to describe the heat generation caused by the friction between a surface of a solid object and high-speed gas flow. This effect is negligible in AHTF.

The AHTF has a number of similar, yet different configurations. The differences are generally in the geometry of the heating chamber and in the duct system for air flow and for supply and return. Figure 1 shows a typical design.

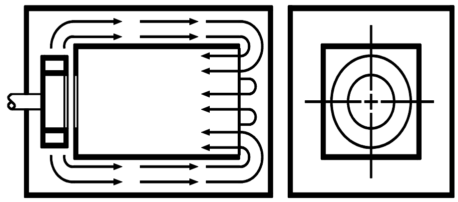


Figure 1. A chamber with a four screen duct system

HEATING TEST

A test to compare the heating ability of three different systems was conducted. An AHTF system, an ERF system and a salt bath system were compared. The duration and uniformity of heating in air and potassium nitrate were recorded with 12 thermocouples equally spaced in the working area. The time for heating various semi-finished products to 500-525^oC was determined with thermocouples in the center of the samples of the 2024 type alloy (sheets 0.8-10 mm thick, pipes with a wall thickness of 1 to 4 mm, bar 40-200 mm in diameter) and the AK6 alloy (forgings 40-100 mm thick). The weight of the metal loaded in the furnace and the salt bath was 80-350 kg.

It was found that the AHTF-3 produces a more uniform temperature field in the working space than the ERF-2, the temperature difference in the working space approaching that in the salt bath (Table 1).

Table 1. General Specifications of Heating Systems

	AHTF-3		ERF-2	Salt bath	
Power kW	55		129	100	
Working Dimensions mm	1100 x 3100 x 1600		1200 x 3200 x 1500	1000 x 3200 x 1100	
Max Operating Temperature, ^oC	550		550	540	
Rate of Air Circulation, m/sec	16-18		6	-	
Heating Temperature, ^oC	160	410	500	500	500
Temperature Uniformity, ^oC	± 1.5	± 2.0	± 3.0	± 5.0	± 2.0

The air is heated from room temperature to 500°C twice as rapidly in the AHTF-3 (4 hr) as in the ERF-2 (8 hr). The higher heating rate was observed for a furnace of the same size even though the ERF-2 had twice the power.
Despite a larger drop in temperature in the AHTF-3 in comparison to the ERF-2 when metal weighing 180-350 kg is placed in the furnaces, the AHTF-3 heats the metal to the given temperature 1.5 to 2 times as rapidly (Fig. 2). However, when the load of metal is 80-160 kg the ERF-2 heats the air to the given temperature 1.5 times as fast as the AHTF-3 (Fig. 3). This is due to the large reserve of heat in the ERF-2 in the mass of the heated brick wall, which also leads to a smaller reduction of the furnace temperature when the metal is loaded into a hot furnace.

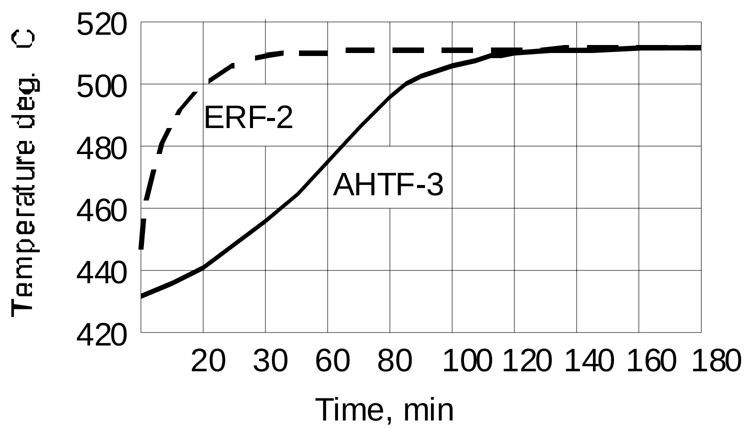


Figure 2. Heating curve of metal from the moment of loading of the furnace to the temperature of 515°C for bars and forgings weighing 350 kg.

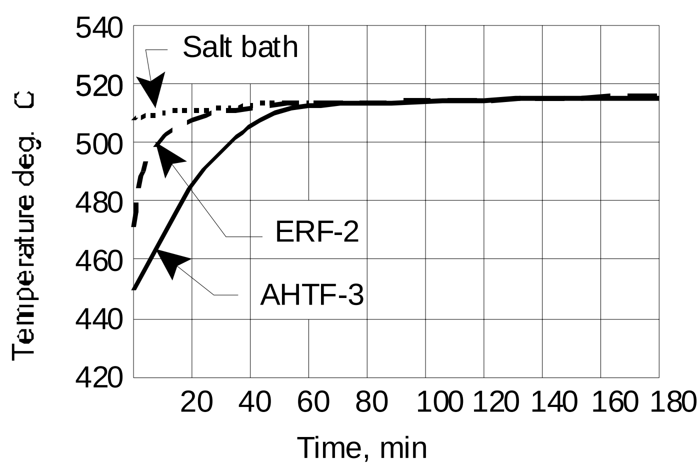


Figure 3. Heating curve of metal from the moment of loading of the furnace to the temperature of 515°C for bars and forgings weighing 160 kg.

The temperature drop of the salt bath when the metal is loaded is minimal because of the large thermal inertia, and the time of heating to a given temperature is maximum by comparison with the ERF-2 and AHTF-3 (Fig. 2). Bars and forgings weighing 160-350 kg are heated to 515□C and sheet and pipe weighing 80-180 kg are heated to 500°C 1.8-2.5 times faster in the AHTF-3 than in the ERF-2 furnace in spite of the more rapid heating of the air in the ERF-2 when the load is small.

The heating time is smallest in the salt bath as compared with the AHTF-3 and ERF-2 (Fig. 4). When bars and forgings weighing 160 kg and 40-200 mm thick were heated to 515°C the heating time was 5-20 min in the salt bath, 40-100 min in the AHTF-2, and 60-180 min in the ERF-2. Then the heating rate of the samples in the salt bath declined sharply and the difference in time for heating to 515C decreased: the heating time in the AHTF-3 was only 1-2.4 times more, and in the ERF-2 2.5-5 times more, than in the salt bath.

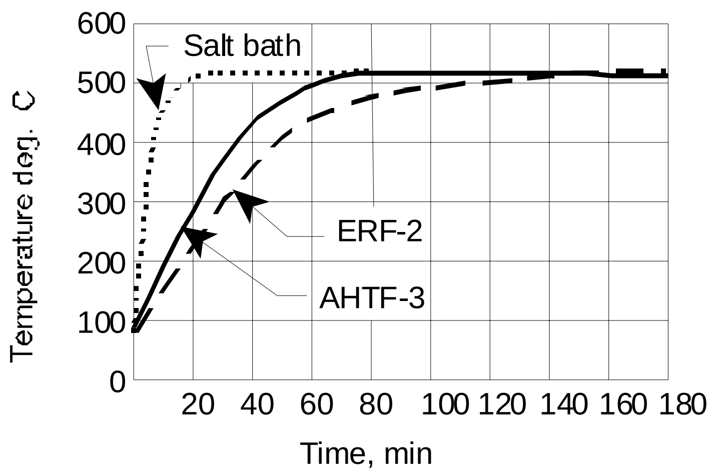


Figure 4. Heating curve of metal from the moment of loading of the furnace to the temperature of 515°C for bars and forgings 100 mm thick weighing 160 kg.

The advantage of the AHTF-3 in the uniformity of the temperature field in the working space and the rate of heating the metal in spite of its lower power (one-half) by comparison with the ERF-2 is explained by the high rate of circulation of the air, the low thermal inertia, the existence of a single thermal zone and the complete absence of heat transfer by radiation. ERF-2 has three independently controlled thermal zones; heat transfer is by radiation and convection.

TECHNOLOGICAL EFFICIENCY AHTF

The advantages of AHTF are uniform and intensive heating. This results in good control of process, with resulting high quality thermal processing (thermo-chemical). Also these units produce a combination of thermal profitability and productivity of the unit, with simplicity of design reliability. An additional advantage of AHTF is that these units give good gas-tightness of the chamber (in contrast to, for example, electric furnaces) eliminating the necessity to support a small positive pressure in the working volume. With normal atmospheric air without protective gasses, when the tightness of the chamber is not required, the pressure is constantly above atmospheric in the unit. As air is always being let out from chamber, inflows are excluded, reducing interim cooling of the load, and increasing uniformity of the heating. All this simplifies the problem of the maintenance of the stable temperature in the air in the work space.

It is important to emphasize the special requirements for uniformity of a temperature field in the heat treatment of materials with space - time uniformity in the development of structural transformations. As a rule the discrete control of the temperature on the surface of a material is used in the heat treatment processes so for a given temperature diagram only points of control are obtained, but phase transitions occur throughout the entire volume of the material. Temperatures at each interior point are not controlled.

HEAT TREATMENT IN AHTF

The results of research and experience with industrial applications testify, not only to the high quality of heat treatment in AHTF, but also the opportunity in a number of cases for significant reduction process cycle times and simplification of procedures with significant decrease in the cost of the process as a whole, and with improvement and increased stability of the material's properties.

Such effects are realized because of the uniformity of heating, accuracy of regulation and maintenance of a temperature mode. The processing with AHTF allows, in a number of cases, one to realize optimum modes unattainable with other methods of heating. For example, the heat treatment of magnesium alloy ML-5 requires heating up to temperature of 420^{o}C with an accuracy of ± 2^{o}C. This furnace allows one to raise the temperature of the metal up to the top limit of hardening temperatures without risk of burning. This has generated a time reduction by one half (from 16 to 8 hours).

The special interest from the point of view of an estimation of quality of heat treatment is represented by aluminum and magnesium alloys, as they are most sensitive to temperature fluctuations: The ability to obtain quantitative parameters on these alloys guarantees the quality of heat treatment of all other materials.

The quality of heat treatment of aluminum deformed alloys was determined by comparison of properties of specimens from different semi-finished products (alloys D16, AK6, V65) (Table 2) after complete strengthening heat treatment with heating to the quench temperature with a AHTF and a saltpeter bath. Specimens from D16 were treated with natural age hardening, from alloys

AK6 and V65 - with artificial aging, from alloys AK6 and V65 - with artificial aging using the AHTF.

Specimens were cut from rolled plates D16, extruded tube and bar D16, forged AK6 billets and pins from V95. The results for tensile strength, σ_b, yield strength, $\sigma_{0.2}$, percent of elongation, δ, shear strength, τ_{sh} for rivets, fracture toughness K_c, electric conductivity of specimens, heat treated in AHTF and saltpeter bath were obtained (Tables 3-5). Losses of mechanical properties due to stress corrosion of plates D16 with thickness 0.8 and 1.5 mm, quenched in water after heating with the AHTF, are less than after heating in the saltpeter bath (Table 2); during the heating to the quench temperature with an AHTF the scattering of properties of specimens (σ_b , δ) was smaller. The depth of diffusion of copper and magnesium into the cladding of alloy D16 specimens with thickness from 0.8 to 10 mm and tube D16 (30 by 15 mm), heat treated in the AHTF and in salt bath were the same.

Table 2. Composition of Wrought Aluminum Alloys, %

	AK6	D16	V65	V95	AK4-1
Cu	2.2	4.3	4.2	1.7	2.4
Mg	0.65	1.5	0.2	2.3	1.6
Zn	-	0.3	-	6.0	0.3
Si	0.9	0.5	-	-	0.35
Mn	0.6	0.6	0.4	0.4	0.2
Cr	0.7	0.5	-	1.18	-
Fe	-	-	-	1.5	1.1
Ni	-	-	-	-	1.1

Investigation of the heating processes in a AHTF for forgings from alloy AK-6, which were produced from preliminary deformed semi-finished products, indicated the possibility of a drastic reduction of the heat treatment cycle times. According to a study of mechanical properties of specimens, cut from forging in three directions (σ_b, $\sigma_{0.2}$, δ) were the practically the same after the heat treatment with a reduced holding time of hold, t = 100 min as compared to the recommended holding time, t = 150 min (Table 4).

The heat treatment (artificial aging) without preliminary quenching, which needs close control on the temperature, of automobile pistons from heat-resistant alloyed AL-30 with the AHTF produced good quality of parts. Optimum processing, such as age hardening with at 185^{o}C for 8 hours and cooling in the air, generated better mechanical and manufacturing properties. The cycle of heat treatment was reduced by 4 to 6 hours, compared with previous technology. Further, for manufacturing conditions, with the heat treatment of big groups (more than 2000) pistons without special placement, positive results were obtain too.

Aging hardening of alloy AK4-1 was also done with a AHTF. The basic problem of those processes is a requirement of high uniformity of heating with a gas temperature variation not more than ± 1 to 1.5^{o}C and at the metal ± 3^{o}C. Optimum temperature of artificial age hardening

: for plates AK4-1 is t = 195 ± 5°C with holding time of τ = 12 h.; for as quenched, t = 192 ± 2°C, τ = 24 h.

Table 3. Fracture Toughness (Kj/m^2 of the Specimens after Heat Treating in the Furnaces.

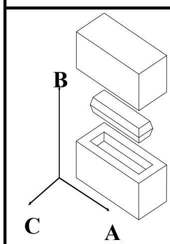
	Sheet, 2024			
Thickness of a sheet, mm	AHTF	saltpeter bath		
		3	7	20
1.5	107.90	107.90	-	95.16
3.0	101.00	94.18	-	91.23
5.0	100.00	96.14	-	88.30
				
Orientation of specimens	Forging AK6			
	AHTF	saltpeter bath		
		3	7	20
B	71.61	-	65.65	-
C	117.72	-	107.90	-
A	196.20	-	166.77	-

Table 4. Electrical Conductivity Σ, of 2024h Aluminum Alloy m/(ohm A mm^2)

Thickness of the sheet, mm	As shipped	After heat treatment in the furnaces:	
		AHTF-3	saltpeter bath
3	16.8	16.8	17.1

5	19.0	19.2	19.4

Table 5. Properties of Specimens after Heat Treatment by Different Heating Methods Before and after Corrosion Tests					
Ultimate Tensile Strength - UTS (MPa) and Percent Elongation - %					
			before	after	change %
Sheet 2024S 0.8mm 1	AHTF	UTS	447.34	302.15	33.9
		%	22.5	4.4	80.5
	Salt bath	UTS	429.7	340.4	20.8
		%	20.2	6.7	67.0
Sheet 2024H0 .8mm	AHTF	UTS	454.2	253.0	54.7
		%	21.9	4.4	80.0
	Salt bath	UTS	449.3	255.0	43.3
		%	21.1	4.0	80.0
Sheet 2024S 1.5 mm	AHTF	UTS	456.16	426.73	6.5
		%	19.7	11.4	42.0
	Salt bath	UTS	435.6	395.34	10.0
		%	18.9	9.2	51.0
Sheet 2024H 1.5 mm	AHTF	UTS	458.13	415.94	9.3
		%	19.3	9.8	49.0
	Salt bath	UTS	451.26	364.93	19.0
		%	19.8	4.6	77.0

AHTF satisfy the tight requirements, which are necessary for the process of heat treatment, and exceed special electro-thermal equipment for medium- and low-temperature heating with regard to quality of treatment, productivity and efficiency of process. AHTFs do not concede to the technology parameters of other methods and sometimes they exceed the most effective heating technologies available.

CONCLUSIONS

- The AHTF is more economical, simpler to manufacture, and safer in operation than electric air furnaces or salt baths.

- The AHTF produces a more uniform temperature in the working space and heats the air from room temperature to the given temperature twice as rapidly as ERFs.
- Heating of different semi-finished products with sections 40-200 mm thick in loads of 80-350 kg to 500-515°C is 1.8-2.5 times more rapid in the AHTF-3 than in the ERF-2 with similar dimensions in spite of the fact that the ERF has twice the power.
- The mechanical properties, resistance to corrosion and stress corrosion, and electrical conductivity of various semi-finished aluminum alloy products are the same after heat treatment in the AHTF-3, ERF-2, and the salt bath.

REFERENCES

1. KOLOBNEV, V and others, Metallovedenie and Termicheskaya Obrabotka Metallov, No. 1, January 1968, pp. 49-51
2. LEMKE R. G. Troubleshooting of Electrical Machines, Moscow-Leningrad, Gosenergoizdat, 1963, 176 pages
3. LOITSYANSKY, L. G. Fluid Mechanics, Moscow, Nauka, fifth edition 1978, 736 pages
4. SOLOMATINA, T. C.. TCHBISHEVA, K. V Centrifugal Fans , Moscow, Mashinostroenie, 1980 176 pages
5. SVERDLIN A., NESS, A. R., DRITS, A., Aerodynamic Furnaces, Advanced Materials & Processes April, 1996 pp. 40-44
6. TEVIS, P. I. ANAJEV, V. A. SHADEK, E. G. Recirculating Aerodynamic Heating Furnaces, Moscow, Mashinostroenie, 1986, 208 pages

