

# The aging mode for reducing the thermal expansion of the piston from alloy AK21

**A N Prudnikov, V A Prudnikov, M V Popova, V K Afanasyev  
and V Ya Zellermayer**

Siberian State Industrial University, 42 Kirova street, Novokuznetsk, 654007, Russia

E-mail: a.prudnikov@mail.ru

**Abstract.** The effect of temperature and aging time (1÷10 h) at 100-300 °C on the microstructure and thermal expansion of the engine piston YaMZ 5363 from the hypereutectic silumin of AK21 type was studied. It is established that low-temperature aging at 100 °C for 1 hour, allows the temperature coefficient of linear expansion (TCLE) to be reduced in the operating temperature range of heavy-loaded engines (250-350 °C) by 3-6%. The increase in the aging time of pistons up to 3, 5 and 10 h does not lead to the further decrease in TCLE, as well as the increase in the aging temperature to 150, 200, 250 and 300 °C. Moreover, low-temperature aging does not lead to significant changes in the structure of the pistons of the engines in the delivery state, with the exception of coagulation of some of the volume fraction of the eutectic component of Al-Si or Al-Si-Cu.

## 1. Introduction

At present the need for powerful and multifunctional cars has increased, which necessitated a balance of fuel economy, durability and reliability of the engine. The automakers always faced the problem of not only constructive changes of parts and the engine itself, but also the development of light materials with improved properties, including mechanical, physical and operational ones. One of the most important parts of the engine is the piston. It withstands mechanical loads from pressure forces of gases and inertia forces, as well as thermal loads from contact of the bottom with hot gases and friction of its lateral surface against the wall of the cylinder. Therefore, high requirements are imposed on piston alloys, such as high thermal conductivity and heat resistance, good antifriction properties, low specific gravity, low temperature coefficient of linear expansion (TCLE). The most widespread among piston alloys for heavily loaded engines were the hypereutectic alloyed siluminins of the Al-Si-Cu-Mg-Ni system cast by various casting methods on chill casting machines. The wide application of these alloys is associated with the complex of their properties.

However, up to now, the full service life of piston alloys used for heavily loaded internal combustion engines has not been developed, especially in the field of physical properties (thermal expansion, thermal conductivity, specific gravity). To improve the structure and characteristics of the ICE pistons uses a variety of processing methods at all stages of their manufacture, from preparation of the charge and ending with the production of the finished product.

In particular, thermal or deformation preparation of charge [1-3]; metallurgical – refining and modifying with the use of reagents and physical methods of influencing the melt in the production of castings and ingots (ultrasonic and electromagnetic processing) [4-12]; special methods of processing thermal, thermocyclic (TP, TCP) [13-16] and deformation-thermocycling treatment (DTCO) [3,7,17-



20]. It is more attractive to use the most economically efficient and effective ones for improving the properties of pistons, and also implemented at the stage of the finished product.

## 2. Methods and materials

The piston of YaMZ 5363 engine manufactured by Yaroslavl Motor Plant of MAZ 5550 series in the delivery state was selected as a study object. The chemical composition of the piston was determined on the emission spectrometer ARL 3460 and is given in table 1.

**Table 1.** Chemical composition of the studied piston.

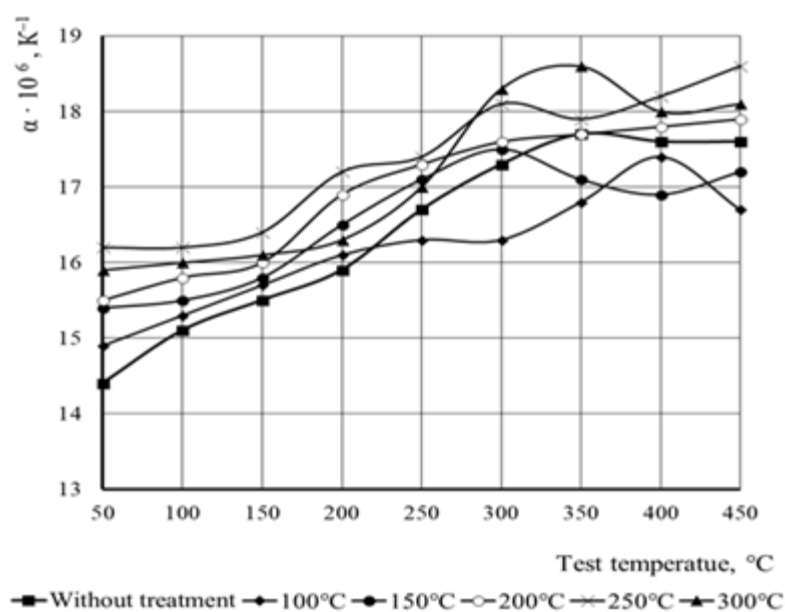
Material	Chemical composition, % (aluminum remaining)								
	Si	Cu	Mg	Ni	Mn	Fe	Cr	Ti	Zn
Piston alloy	22.1	2.91	0.64	1.23	0.08	0.49	0.26	0.08	0.01

The composition of the studied alloy corresponds to the composition of the piston hypereutectic silumin AK21M2.5H2.5 (GOST 1583-93) and differs somewhat less in nickel, manganese and slightly magnesium, which is due to the requirements of the company specification. Samples cut from the piston skirt were subjected to thermal treatment (aging) in SNOL-1,6.2,5.1/9-I3 electric furnace in the following modes: heating and holding for 1÷10 hours at 100 and further through 50 °C to 300 °C with cooling in the air.

Metallographic studies were carried out on the optical microscope LaboMet-II. For dilatometric analysis, a high-temperature optical differential dilatometer of DIL type was used. When determining the true value of TCLE, the error of the method was  $1 \cdot 10^{-6} \text{ K}^{-1}$ .

## 3. Results and discussion

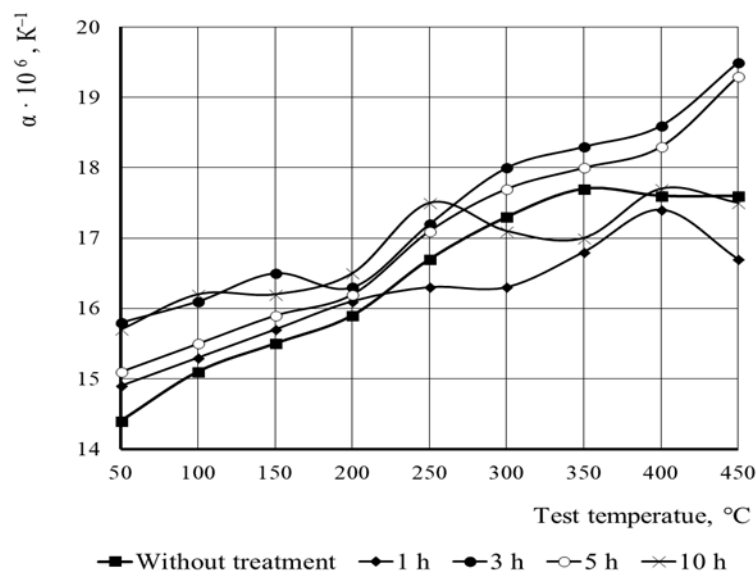
The results of the study of the effect of the aging temperature in the interval 100-300 °C after 50 °C with the holding time of 1 hr for the TCLE of the piston of the YaMZ engine from the AK21 alloy are shown in figure 1.



**Figure 1.** Influence of the aging temperature with a holding time of 1 h on the linear expansion of the piston from AK21 alloy.

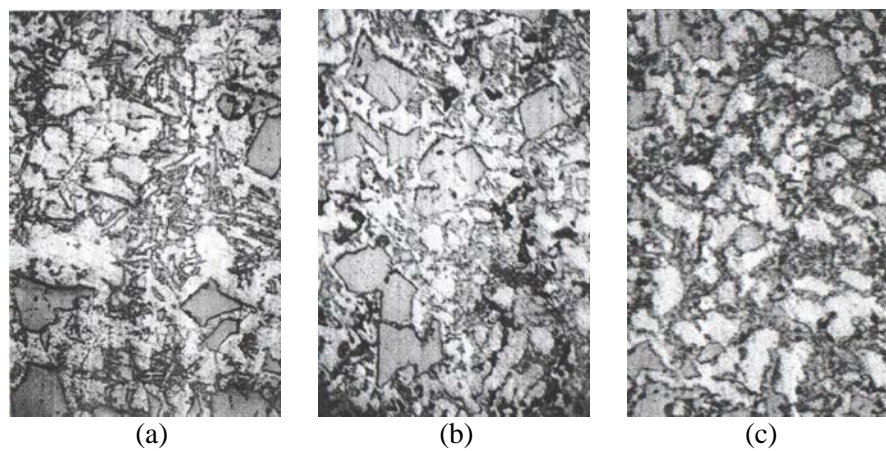
Analysis of the  $\alpha$ -T curves showed that aging at temperatures above 100 °C with a holding time of 1 h increases the value of the TCLE of the piston alloy as compared with the alloy without thermal treatment throughout the temperature range of the tests. The magnitude of this increase for each aging temperature is different. Thus, for aging temperatures of 150 and 200 °C it is on average  $2 \div 7\%$ , for temperatures 250 and 300 °C –  $1.1 \div 12$  and  $1.8 \div 10\%$  respectively. For low-temperature aging (100 °C) of samples from the piston, a different change in the magnitude of the thermal expansion is noted. In the low-temperature range of the piston operation (up to 200 °C) the TCLE slightly increases by an average of  $1 \div 3\%$  relative to the initial state of the alloy. At high engine operating temperatures (above 200 °C) the capacity of piston alloy to expand is reduced by an average of  $3 \div 6\%$  in the range  $250 \div 350$  °C compared to non-heat-treated alloys.

The consequent increase in the holding time of the samples from the piston at the most promising temperature of 100 °C (see figure 1) to 3, 5 and 10 h does not lead to a further decrease in TCLE over the whole temperature range of the test (figure 2). The tendency to increase the value of thermal expansion with increasing aging time in the aging process is almost the same as the temperature factor. Moreover, the maximum increase in TCLE of the piston alloy corresponds to the greatest aging time (10 h) at 100 °C and is from 3 to 7.5% for operating temperatures of 20-300 °C compared to samples aged for 1 h. And only at the test temperature 350 °C increase in TCLE becomes insignificant (about 1%).

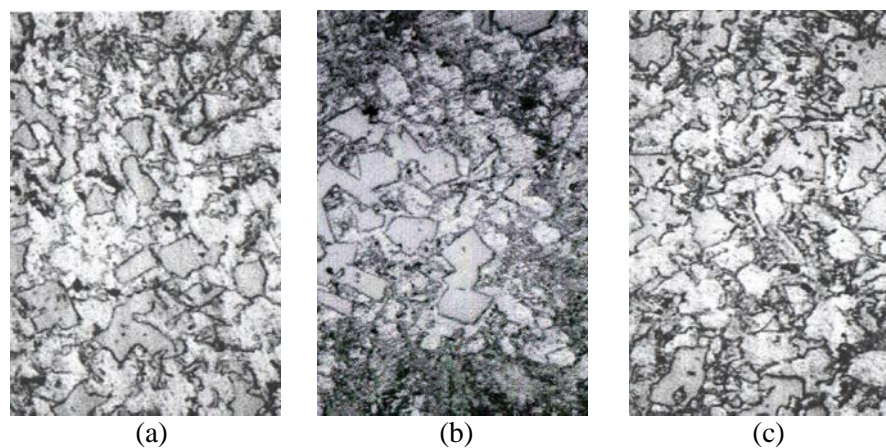


**Figure 2.** Influence of the aging time at the aging temperature of 100 °C on the linear expansion of piston from AK21 alloy.

The piston alloy of YaMZ engine has a rather complex phase composition, which is characteristic for casting piston hypereutectic siluminins such as AK21. The main structural components of the piston silumin are  $\alpha$ -solid aluminum solution ( $Al_\alpha$ ), primary silicon crystals  $Si_\beta$ , aluminum-silicon eutectic ( $Al + Si$ ). In addition, copper-containing phases are present in the structure, first of all, the strengthening phase of  $W-CuSi_4Mg_5Al_4$  and a certain amount of  $CuAl_2$ . Phases containing Ni and Mg and more complex eutectics based on Al, Ni, Fe, Si are also detected. In the structure of the investigated piston, the CPSs have an average size of 30-64  $\mu m$  and are fairly evenly distributed in the piston structure, and the size of the CPSs is larger in the bottom of the piston than in crystals in the skirt. This is primarily due to the greater thickness of the bottom and, correspondingly, the lower cooling rate during crystallization of the billet in the chill mold. The microstructure of the piston alloy after aging at 100-300 °C for 1 hour is shown in figure 3, and the effect of holding time during aging from 1 to 10 hours is shown in figure 4.



**Figure 3.** Effect of aging temperature on the piston microstructure of AK21 alloy (holding time 1 h); a – without treatment, b – 100 °C, c – 300 °C,  $\times 300$ .



**Figure 4.** Effect of aging time at the aging temperature 100 °C on the piston microstructure made of AK21 alloy; a – 1 h, b – 5 h, c – 10 h,  $\times 300$ .

It can be noted that as the aging time increases, a certain fragmentation and spheroidization of the eutectic silicon takes place. Moreover, the higher the aging temperature, the earlier this process begins in time and proceeds more intensively. However, holding for 1 hour at the aging temperature 100 °C is not sufficient for a significant change in the structure of the piston silumin. Thus, it has been established that practically neither time nor temperature has a significant effect on the size and distribution of CPSs, the size of which remains within 30-64  $\mu\text{m}$ , which is apparently associated with a low aging temperature 100-300 °C for hypereutectic silumin.

#### 4. Conclusion

As a mode for reducing the linear expansion of the piston from AK21 alloy, it is possible to recommend additional low temperature aging at 100 °C for 1 hour, which makes it possible to reduce the TCLE in the operating temperature range of heavy-loaded engines (250-350 °C) by 3-6%. And low-temperature aging does not lead to significant changes in the structure and properties of engine pistons.

#### References

- [1] Prudnikov A N 2014 *Technology of Metals* **3** 16–22

- [2] Puga H, Barbosa J, Soares D, Silva F and Ribeiro S 2009 *J. of Mat. Proc. Tech.* **209(11)** 5195–203
- [3] Prudnikov A N 2013 *Structural and Technological Basis for the Development of Precision Silumin with Regulated Hydrogen Content* (Novosibirsk: NSTU) 40
- [4] Deyev V B et al 2008 *Polzunovsky Almanac* **3** 77–81
- [5] Prudnikov A N 2009 *Foundry Production* **2** 2–5
- [6] Friedrich B and Kräutlein C 2006 *Metallurgija - Journal of Metallurgy* **12(4)** 252–266
- [7] Prudnikov A N 2014 *Deformation and Destruction of Materials* **2** 14–20
- [8] Naidek V L, Narivsky A V 2008 *Improving the Quality of Aluminum and Copper Alloys Castings by Means of Plasmareagent Treatment of Melts* (Kiev: Naukova Dumka) p 183
- [9] Prudnikov A N 2009 *Metallurgy of Machine-building* **3** 28–31
- [10] Deyev V B et al 2012 *Foundry* **5** 16–18
- [11] Prudnikov A N 2009 *Metal Processing* (Technology, Equipment, Tools) **2** 26–31
- [12] Grachev V A and Turakhodjaev N D 2017 *Archives of Foundry Engineering* **17(4)** 61–66
- [13] Taskin M, Orhan M and Ozan S 2006 *J. of Engineering Mater. Sci.* **12** 362–7
- [14] Prudnikov A N 2004 *Izv. Vuzov. Ferrous Metallurgy* **4** 40–2
- [15] Song D, Kang G and Kan Q 2014 *Smart Materials and Structures* **23(1)** 1–7
- [16] Prudnikov A N 2009 *Metal Processing* (Technology, Equipment, Tools) **1** 8–11
- [17] Furuya Y and Park Y 1992 *Nondestructive Testing and Evaluation* **8(1)** 541–54
- [18] Prudnikov A N and Prudnikov V A 2015 *Metallurgy: Technologies, Innovations, Quality* vol 2 (Novokuznetsk: SibSIU) pp 15–18
- [19] Fedyukin V K and Smagorinsky M E 1989 *Thermocyclic Processing of Metals and Machine Parts* (Leningrad: Mechanical Engineering) p 255
- [20] Yu T, Wang L and Zhao Y Q 2012 *International Journal of Fatigue* **35(1)** 31–36