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A New Method for Producing Finned Heat Sinks for Electronic Applications

Abstract. *The paper presents new methods for forming heat sinks by forging. In the first part of the paper, an overview of methods for producing heat sinks is given, and the most common industrial applications of heat sinks are presented. The paper then examines the problem of producing such products by forging with the use of a three-slide forging press. The paper also presents the assumptions underlying the method for producing heat sinks which was developed at Lublin University of Technology and claimed under Patent Application No. P. 404274 of June 10, 2013.*

Streszczenie. *W opracowaniu przedstawiono nowe możliwości kształtowania radiatorów metodą kucia. W pierwszej części opracowania przeprowadzono przegląd metod wytwarzania radiatorów oraz podano ich najczęstsze zastosowanie w przemyśle. W dalszej części przedstawiono analizę stanu zagadnienia w zakresie możliwości kucia tego typu wyrobów przy wykorzystaniu trójsuwakowej prasy kuźniczej. W niniejszym artykule przedstawiono założenia metody wytwarzania radiatorów opracowanej w Politechniki Lubelskiej zawartej w zgłoszeniu patentowym nr P. 404274 z dnia 10.06.2013 r. (**Nowa metoda wytwarzania radiatorów z żebrami do zastosowań w elektronice**).*

Keywords: heat sink, electronics, forging, three-slide forging press.
Słowa kluczowe: radiator, elektronika, kucie, trójsuwakowa prasa kuźnicza.

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Introduction

Heat sinks are one of the most popular cooling systems. Also, they are one of the simplest devices for dissipating heat from components and electronic systems. The development of electronics is nowadays inextricably linked to the development of materials for heat sinks, heat sink design and production methods. Heat sinks can be produced by a number of methods depending on their use. Thermal resistance is the key parameter when deciding on the use of a radiator. A value of this parameter is affected by many factors, including surface area of a radiator, radiator shape, colour of the surface, air flow and heat sink temperature [1]. In industrial practice, air heat sinks are mainly produced by extrusion, pressing and casting methods. Still, research is made on new technological solutions that will lead to producing parts with enhanced quality and higher functional properties.

This study presents a new method for producing heat sinks by the forging process in a three-slide forging press (TSFP). Equipped with three independently working slides, the press offers far more forming possibilities compared to other multi-tool machines. The application of the new proposed method for producing heat sinks results in substantial material savings and obtaining products with higher strength properties. Examples of heat sinks that can be produced by the new TSFP-based method are shown in Fig. 1.

a) b) c)

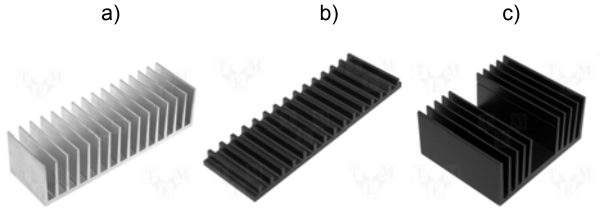

Fig. 1. Finned heat sinks: a) aluminium extruded heat sink; base dimensions: 60 mm X 190.5 mm, fin height: 50 mm, b) aluminium extruded and anodized heat sink; base dimensions: 50 mm X 159 mm, fin height: 10 mm, c) aluminium extruded and anodized heat sink; base dimensions: 100 mm X 120 mm, fin height: 50 mm [2]

Overview of methods for producing heat sinks

Heat sinks can nowadays be produced by processes such as extrusion, drawing, pressing, casting, welding, assembling or machining. The most widely applied method for forming heat sinks is pressing that is thoroughly described in the study by E. Raj [3]. Heat sinks produced thereby are made of a specially formed grooved aluminium or copper plate. Heat sinks in the form of forgings are made for low and medium power components. Their thermal resistance ranges between 1 ÷ 100 K/W. Forgings dissipate heat via natural convection. The surface of such heat sink is often subjected to surface treatments such as oxidizing, blacking or anodizing. After surface treatment, heat sinks exhibit a decrease in thermal resistance by 10% ÷ 45%. Forgings are one of the cheapest solutions for electronics cooling systems.

The extrusion method is applied to produce profiles for heat sinks. A heat sink is produced by cutting a profile being extruded to the desired dimensions; then, smooth or threaded holes that serve for attaching electronic components are made in it [4]. Heat sinks are most often made of aluminium alloys. The minimum thickness of fins in such heat sinks is approximately 0.64 mm (standard fin thickness is approx. 1.5 mm), while the maximum height-to-distance ratio between fins is 10:1 (standard ratio is 6:1 or 8:1). The thermal resistance of extruded heat sinks ranges between 0.08 ÷ 15 K/W. Such solutions are used for dissipating heat via natural convection or forced convection when air flow is forced by applying an additional fan or fans. Extruded heat sinks are subjected to anodizing; after this surface treatment their thermal resistance decreases by 20% at natural convection and to 4% ÷ 8% at forced convection. The method for extruding heat sinks is described in detail by S. Lee in the study [5].

Heat sinks can also be produced by drawing, this process being described in detail by S. Lee [6]. Heat sinks are produced by deep drawing from sheet metal plates.

Another method for producing heat sinks is based on welding techniques, which is described in American Patent No. 006564458B1 [4]. The method described therein consists in joining heat sinks components (i.e. fins to the rectangular section base) by soldering at low temperature. The technology is characterized by low manufacturing costs; it also prevents fins from thermal distortion owing to the fact that the soldering process is run at low temperature. One more method for producing heat sinks by welding materials consists in joining fins to the plate using thermally conductive adhesive based on silver powders, as described by M. Kowalik and T. Trzepieciński [4]. Fins are most often bonded to the base by means of adhesives based on epoxy resins. Heat sink components for welding are made of copper or aluminium. Their parameters are the following: fin thickness ranges from 0.7 mm to 2.5 mm, while the maximum height-to-distance ratio of fins is 30:1. Compared to heat sinks produced by drawing, welded heat sinks exhibit an increase in active surface by two or three times. Their thermal resistance ranges between 0.1 ÷ 0.6 K/W (natural convection amounts up to 2 K/W). They can be used in the case of power losses amounting to 200 W. Heat sinks of this type are used for dissipating heat via natural and forced convection.

Assembling is another popular method for producing heat sinks. Heat sinks produced thereby are made of plates with milled grooves wherein sheet fins can be mounted. An example of assembling such cooling systems is described in American Patent No. 20120227952A1 [7]. Heat sinks produced by said method are most often made of aluminium, copper, bronze, Inconel, stainless steel. They have a fin thickness ranging between 0.5 mm and 1.2 mm. The maximum height-to-distance ratio of fins is 40:1, while the fin height amounts up to 100 mm. Thermal resistance of such heat sinks ranges between 0.02 ÷ 0.8K/W. They dissipate heat via natural and forced convection. Cooling systems of this type have been created for the purposes of military and aircraft industry applications. The construction of assembled heat sinks are extremely light and have substantial volumetric thermal capacity.

Heat sinks can also be produced by casting, as is described in the study by T. Fuxiang and W. Mingrong [8]. Heat sinks produced by casting have closely packed pin-shaped fins, which allows obtaining very high thermal parameters at impact cooling. They are made of pure aluminium or aluminium alloys. They exhibit the following parameters: fin thickness is 0.5 mm, max. fin height is up to 80 mm. Their thermal resistance ranges between 1.5 ÷ 25 K/W at natural convection, and 0.1 ÷ 8 K/W at forced convection.

One more method employed in industrial practice to produce heat sinks is machining, which consists in forming a surface into the desired shape, dimensions and surface quality by removing material from a cuboid workpiece using cutting tools. The main technique for doing this consist in milling grooves between fins, which is thoroughly described by M. Kowalik and T. Trzepieciński in the study [4].

Description of heat sinks and their industrial applications

Heat sinks are widely used in various sectors of industry, such as electronics, aircraft and automotive industries, and others. Fig. 2 shows the most important industrial applications for heat sinks.

Fig. 2. Industrial applications for heat sinks

A heat sink is a specially formed body made of a metal with high thermal conductivity or its alloys. The main role of heat sinks is to carry away and then dissipate heat to environment from an element they contact via conduction or radiation. Heat sinks are used to protect devices from damage caused by too high temperatures. The construction of a heat sink is very important. Usually, a heat sink has a more developed surface from the side of the medium (e.g. air) that surrounds it. In order to increase heat transfer by a heat sink, fns and rods of various shapes (rectangular, round, triangular, etc.) can be used [9]. The number of fins, their shape or height affect the efficiency of the cooling system. Examples of heat sink profiles of various shapes and fin types are shown in Figs. 3 and 4.

a) b) c)

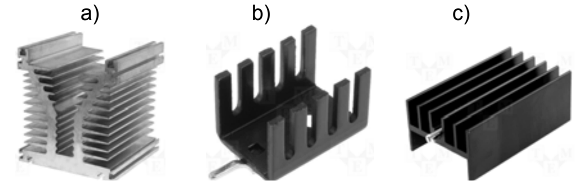

Fig. 3. Examples of heat sinks: a) Y-shaped (aluminium extruded), b) U-shaped (aluminium pressed and anodized), H-shaped (aluminium extruded and anodized) [2, 10]

a) b) c)

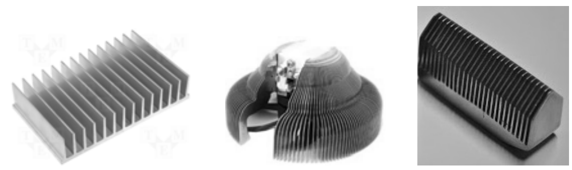

Fig. 4. Finned heat sinks: a) rectangular fins, b) semi-circular fins, c) triangle fins [2]

Air heat sinks are made of aluminium and copper. Parameters of the materials used for the production of heat sinks are listed in Table 1 [11]. The key role in material selection is thermal conductivity, which describes the property of a material to conduct heat. Sometimes, materials with high thermal conductivity are not used due to economic reasons. To ensure better heat conduction, a heat sink is pressed down to a heat-emitting surface. If any gap occurs, it is filled up with a thin layer of a paste or thermally conductive adhesive. Properties of a heat sink can be additionally enhanced by subjecting aluminium to oxidizing, blacking or anodizing, after which the surface of aluminium exhibits higher infrared radiation emission capacity.

Aluminium and its alloys are the most often used material for the production for heat sinks. Aluminium has high thermal conductivity; it is light and relatively easy to process. Another widely used material is copper whose thermal conductivity is approximately two times higher than that of aluminium; yet copper is about three times heavier and about four to six times more expensive than aluminium. In contrast to aluminium, too, copper drawing can cause problems [9].

Table 1. Materials for heat sinks

Material type	Thermal expansion coefficient [ppm]	Thermal conductivity [W/mK]	Heat flow kg/m3]
Aluminium	23	204	2710
Copper	17	390	8960
Copper-Molybdenum	7.2	195	-
Copper-Graphite	2	350	-
AlSiC	6.5-8.0	180-210	3000

Source: developed by the authors based on [11]

Heat sinks made of two materials are more and more often used, which results in a lower price of such heat sinks. One of the most popular material combinations for the production of such cooling systems is that of copper-aluminum [12-13]. This solution leads to better efficiency compared to heat sinks made of aluminum only. Heat sinks can be used in free (passive) cooling systems, as they dissipate heat via natural convection. Such cooling systems do not require the use of fans to force additional air circulation. The advantages of this solution include silent work and no need for electric power supply. The shortcoming of this cooling system is its relatively low efficiency, which means that passive cooling does not cool hot elements sufficiently.

Heat dissipators (heat sinks) are also used in forced (active) cooling systems when the air flow is enhanced by the application of an additional fan [14]. The role of such fan is to force air circulation between heat sink fins, which leads to a decrease in the temperature of the device. Active cooling is more effective than passive cooling, yet it requires an additional power supply and generates noise.

Design of the process for forming heat sinks in a three-slide forging press

It was assumed that heat sinks would be formed in a three-slide forging press (TSFP) designed at the Lublin University of Technology, equipped with three moving working tools. Fig. 5 shows the view of a TSFP. Given the capacity of this press, a process for forging heat sinks in this machine was designed (Figs. 6a-10).

Fig. 5. Photograph of a three-slide forging press

At the initial stage of forming a heat sink in a TSFP, the billet in the form of a plate is heated in a furnace to a hot forging temperature. Next, the billet is placed in a closed impression formed by a bottom plate, immovable die, sliding die and two side support plates (Fig. 6a). The sliding die moves towards the immovable die and upsets a section of the semi-finished product, thereby forming the first fin of the heat sink (Fig. 6b).

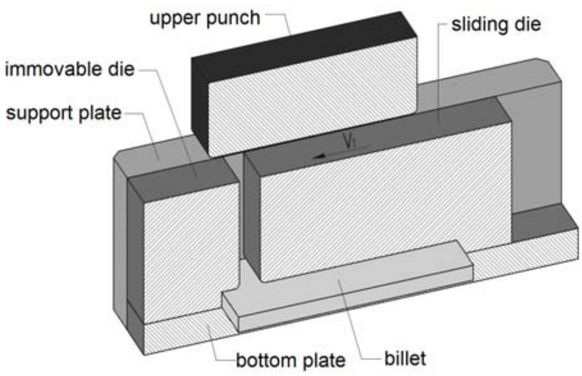

Fig. 6a. Initial stage of forming a heat sink in a TSFP

Next, the sliding die is retracted from the formed semi-finished product. During the successive stage of the process, the semi-finished product with one fin is reheated and put again in the workspace; additionally, a little block is put between the formed semi-finished product and the sliding die.

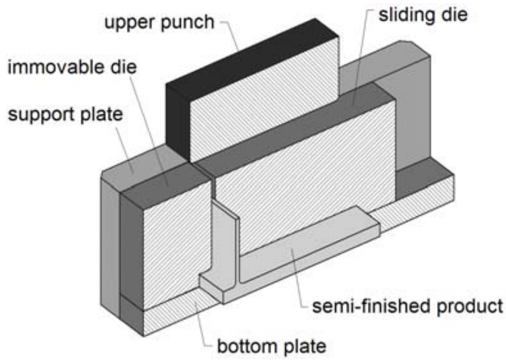

Fig. 6b. TSFP-formed heat sink with one fin

In addition, a separator is placed at a flank of the formed fin (Fig. 7a). The upper punch presses the separator down to the semi-finished product. The sliding die is set into a translational motion, towards the immovable die, and another section of the semi-finished product is upset to the upper part of the impression space, and so the second fin is formed (Fig. 7b).

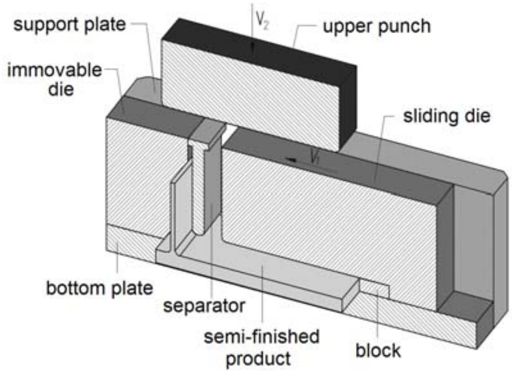

Fig. 7a. Initial stage of forming the second fin of a heat sink in TSFP

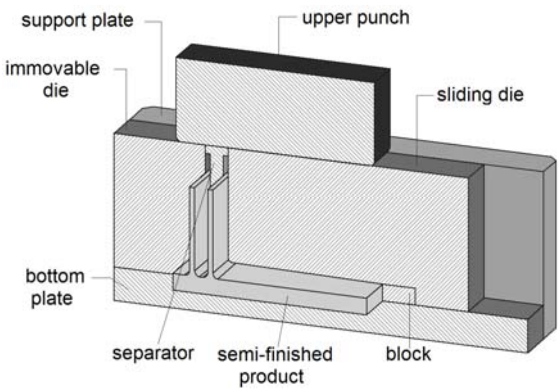

Fig. 7b. TSFP-formed heat sink with two fins

After that, the motion of the sliding die and upper punch is changed; the two tools are retraced from the formed semi-finished product. After reheating, the two-finned semi-finished product and the separator are put in the workspace again. Additionally, two blocks are placed between the semi-finished product and the sliding die, while another separator is placed at a flank of the formed second fin. Then, the separator is pressed down to the semi-finished product by the upper punch (Fig. 8). After that, the sliding die is set into motion towards the immovable die, and another section of the semi-finished product is upset to the upper part of the impression. As a result, the third fin is formed. This pattern is then repeated to form other fins of the semi-finished product until the heat sink reaches the desired dimensions (Figs. 9-10).

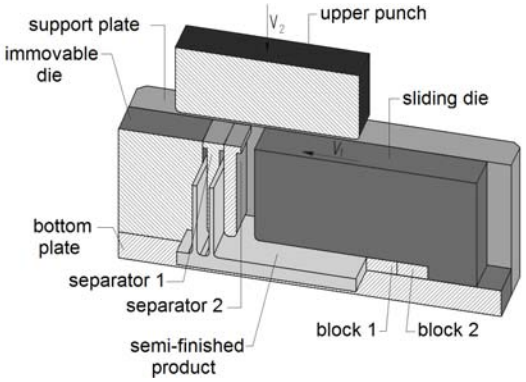

Fig. 8. Initial stage of forming the third fin of a heat sink in a TSFP

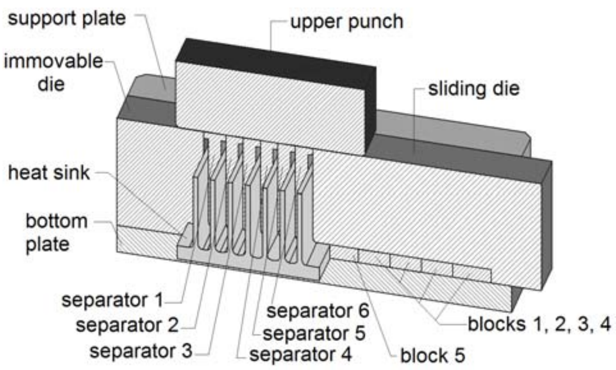

Fig. 9. Final stage of forming a heat sink in a TSFP

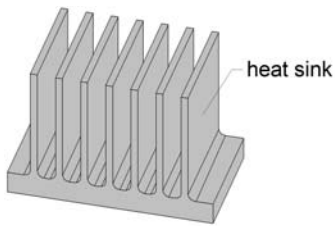

Fig. 10. Heat sink formed in a three-slide forging press

Given the results of the research on investigating the new forming method for heat sinks, it was considered justified that a patent application be applied for. The new technological solution was filed with the Patent Office of the Republic of Poland as “A method for forming a heat sink" under P. 404274 [15].

Conclusions

The study presented the problems related to forming heat sinks by the forging process. The process was conducted in a three-slide forging press that is equipped with three independently moving slides; as a result, the press offers more possibilities of forming compared to other forging machines. One benefit of the new method is that heat sinks can be produced by the forming process. Products obtained from forming have better grain structure, so heat sinks produced thereby exhibit good mechanical and functional properties. Another advantage of the new method is low cost of manufacturing simple forming tools. In addition, the new method for producing heat sinks by flashless forging allows considerable material savings compared to finished products produced by the machining method. This, consequently, leads to decreasing pollution of natural environment as the amount of materials for recycling and utilization is decreased. One more benefit of the new technique for forming heat sinks is that heat sinks produced thereby have shapes and dimensions vary similar to heat sinks produced by other methods. The production of the analyzed cooling systems by the forging method allows obtaining heat sinks with fins of uniform height. Finally, it should be mentioned that the new technology is universal, and it can be employed to form heat sinks made of different materials used in metal forming processes. Given the above-mentioned advantages of the new technique for forming heat sinks when compared to other production methods, it is thus justified that further theoretical and experimental research be conducted.

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