Scientific Research Publishing

Journal of Applied Mathematics and Physics, 2026, 14(5), 2013-2018
https://www.scirp.org/journal/jamp
ISSN Online: 2327-4379
ISSN Print: 2327-4352

Process Optimization from Machining to Casting for Lead Cones Used in the Terminal-Peak Sawtooth Shock

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How to cite this paper: Guo, C.X., Liu, J.Y., Liu, Z.L., Leng, J.P., Hou, H.B., Deng, Q.H. and Ge, Y.Q. (2026) Process Optimization from Machining to Casting for Lead Cones Used in the Terminal-Peak Sawtooth Shock. *Journal of Applied Mathematics and Physics*, **14**, 2013-2018.
https://doi.org/10.4236/jamp.2026.145097

Received: April 20, 2026
Accepted: May 26, 2026
Published: May 29, 2026

Abstract

To reduce the cost of the terminal-peak sawtooth shock tests while satisfying technical specifications, this study explores the feasibility of replacing machining with casting for lead cones used in the terminal-peak sawtooth shock. The results show that the terminal-peak sawtooth shock pulses produced by the cast lead cones satisfy test requirements. Meanwhile, the casting route exhibits superior material utilization efficiency, lower production cost, and simpler process flow. Compared with the traditional machining, the manufacturing cost of the 0.5 kg lead cone processed by the casting has decreased by 60.73%.

Keywords

Lead Cone, Casting, Process Optimization

1. Introduction

To assess the functional reliability of aerospace products, these products must undergo shock environment tests [1]. The terminal-peak sawtooth shock test is a widely used method for shock motion tests [2] [3]. Currently, both at home and abroad, the terminal-peak sawtooth shock test is usually conducted by combining a lead cone with a drop-type shock test bench [4]. Specifically, the deformation of the lead cone is utilized to generate the terminal-peak sawtooth shock pulse. Consequently, the size and shape of the lead cone directly influence the accuracy of test data. However, there are no overly strict requirements for the mechanical properties of the lead cone material.

At present, the production of lead cones generally adopts the traditional bar cutting process. Although this process can ensure the dimensional accuracy of components, it has some disadvantages. Firstly, the material utilization rate is low.

The cutting process is of the "removal type", removing a large amount of unnecessary material from lead bar raw materials. The generated waste cannot be directly recycled, leading to raw material waste. Secondly, lead cones are disposable consumables. They have high demand and a long production cycle, making it difficult to meet mass production requirements. Thirdly, the production cost is high. Excess material loss, as well as labor and equipment consumption from multiple processes, keeps the processing cost of each lead cone at a high level.

Casting is a manufacturing process in which molten metal is poured into a mold cavity and allowed to cool and solidify, yielding finished components or blanks [5]. It has the advantages of simple processes, high material utilization rate, high production efficiency, and low production costs for large-scale production of metal parts. It is widely used in the mass production of metal parts. Therefore, this study takes cost reduction as the core objective, focusing on the research and trial production of lead cones. It explores the feasibility of the casting and provides both theoretical and practical support for optimizing the production of lead cones used in the terminal -peak sawtooth shock tests.

2. Introduction to the Structure of the Lead Cone

During shock testing, the product is secured to a platform. The platform is raised to a prescribed height and then suddenly released, allowing the product and platform to fall freely onto a lead cone. Upon shock, the lead cone is loaded and generates a reverse acceleration. The resulting acceleration curve presents a terminal-peak sawtooth waveform [6]. The configuration of the test bench is shown in **Figure 1**.

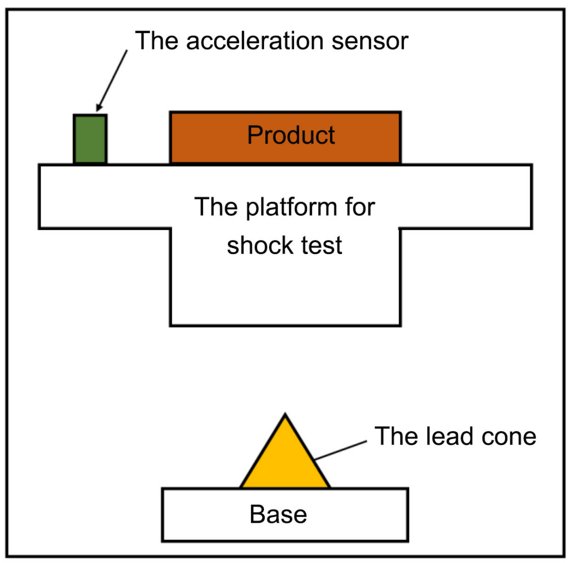

Figure 1. The drop-type shock test bed [6].

The lead cone used in the drop shock test bench is generally a conical shape [7], as shown in **Figure 2**. After being shocked, the lead cone undergoes plastic deformation and cannot be reused, thus it is a one-time consumable item. The physical image is shown in Figure 3.

Figure 2. The lead cone model.

Figure 3. The physical diagram of the loss of the lead cone.

3. Design and Implementation of Casting Processing Plan for Lead Cones

Lead cones are fabricated from metallic lead. This material exhibits a low melting point and excellent melt fluidity, making it highly suitable for casting. Lead ingots are heated and poured into the mold cavity. When preparing the ingredients, raw lead materials are loaded into the furnace. Upon complete melting, the molten metal is stirred immediately to ensure homogeneous composition and uniform temperature distribution. This is beneficial for accelerating the melting of the furnace materials. After confirming that the furnace materials have completely melted, remove the slag. When no floating slag remains on the melt surface, the molten lead is held prior to casting. The casting process flow is shown in Figure 4.

4. Results

During casting, all raw materials are fully melted into liquid phase at high temperatures. Therefore, the scrapped lead cones following shock tests can be reprocessed via casting. This allows material reuse and realizes the recycling of raw lead resources.

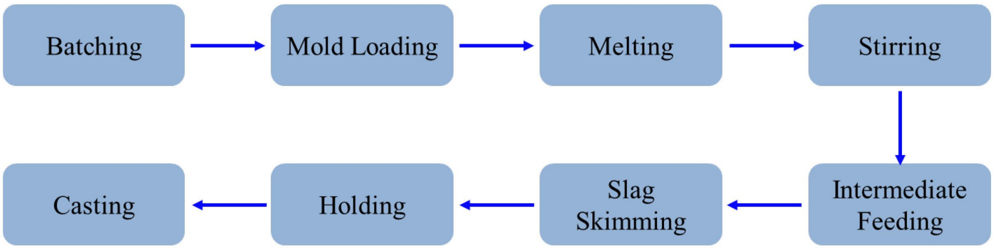

Figure 4. The flow of melting and casting process.

Using the casting, lead cones of three specifications (1.5 kg, 1 kg, and 0.5 kg) have been successfully produced. The corresponding molds and qualified lead cone products are displayed in Figure 5. In accordance with the specified requirements, the height, bottom diameter and appearance of the lead cone were inspected. Inspection results confirm that their dimensional accuracy and surface quality satisfy the design requirements.

Figure 5. The physical picture of the molds and the cast lead cones.

To verify whether cast lead cones satisfy the requirements of terminal-peak sawtooth shock tests, the cast lead cones were used as waveform generators and tested in conjunction with drop-test shock machine. It is well recognized that the specification requirements for terminal-peak sawtooth pulses are determined by the mechanical performance of the test product, which also serves as the evaluation criterion for pulse characteristics. A typical product was selected as the research object, with designated technical indicators including a peak acceleration of (15 ± 1.5) g and a pulse width of (30 ± 3) ms. Corresponding lead cones were manufactured by the casting, and subsequent verification experiments were carried out to validate their performance. The terminal-peak sawtooth acceleration pulse obtained from the verification test is presented in Figure 6. The peak acceleration is 14.86 g, with a pulse width of 28.75 ms. It can be observed that the test results meet the requirements.

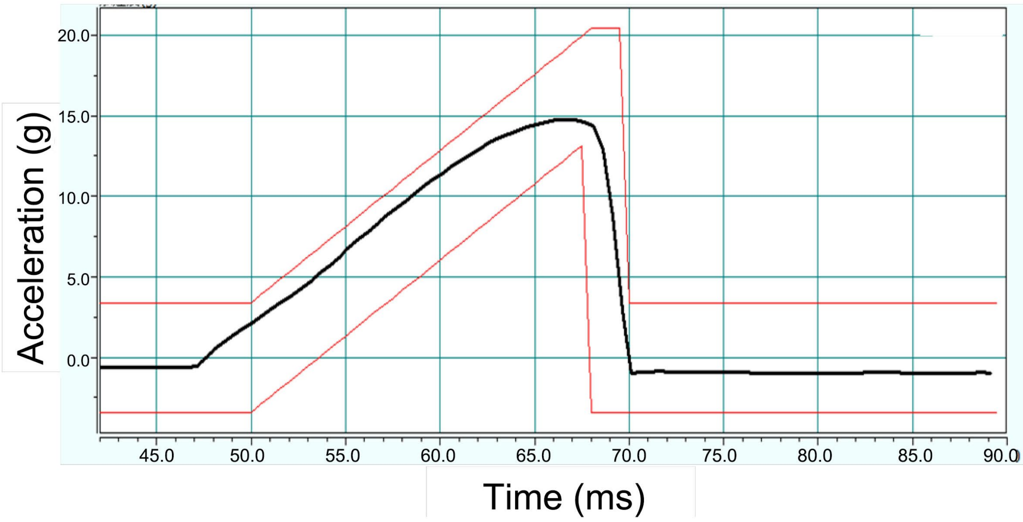

Figure 6. The terminal-peak sawtooth pulse produced by a cast lead cone.

5. Discussion

5.1. Increase in Material Utilization Rate

The lead cone is a conical geometry and is conventionally manufactured via machining. The theoretical material utilization rate is 1/3, while the actual rate from production is only 28%. Furthermore, lead cones deformed during shock tests cannot be re-machined. Thus, the machining method prevents material reuse.

Casting involves melting metallic raw materials into a liquid phase, then poured into a mold to cool and form. During the casting process, the waste residue is removed and discarded. However, the unqualified components and the lead cones that were deformed during the tests can be re-melted and re-cast, enabling material recycling and further enhancing utilization efficiency. Through statistical calculations, the material utilization rate of melt casting reaches approximately 90%, which is significantly higher than the 28% achieved by conventional machining.

5.2. Reduction in Costs

Through process optimization, the manufacturing route for lead cones was converted from machining to casting, resulting in a significant reduction in processing costs. The production cost of lead cones mainly consists of manufacturing costs (including labor costs, mold amortization, etc.) and raw material expenses. Detailed data are provided in Table 1. For a 0.5 kg lead cone, the unit cost decreased from CNY 60 to CNY 23.56, representing a reduction of 60.73%. For a 1 kg lead cone, the cost dropped from CNY 112 to CNY 44.11, a reduction of 60.61%. For a 1.5 kg lead cone, the cost dropped from CNY 165 to CNY 66.67, a reduction of 59.60%.

Table 1. A cost comparison table before and after process optimization for a lead cone.

The specifications of the lead cone		0.5 kg	1 kg	1.5 kg
Machining	Manufacturing Cost	10	12	15
	Material efficiency	28%	28%	28%
	Material cost	50	100	150
	Unit cost	60	112	165
Casting	Manufacturing Cost	8	13	20
	Material efficiency	90%	90%	90%
	Material cost	15.56	31.11	46.67
	Unit cost	23.56	44.11	66.67
Rate of cost reduction		60.73%	60.61%	59.60%

6. Conclusion

This study investigates the feasibility of fabricating lead cones for terminal-peak sawtooth shock using casting. Experimental validation confirms that the shock pulse generated by cast lead cones satisfy the technical specifications. Relative to conventional machining, it is clear that casting substantially improves material efficiency and considerably reduces production cost. Therefore, the casting process is proven feasible for the manufacture of lead cones.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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