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The Rapid Development of Technology in Making Iron Clamps of Three Ancient Temples in the Archaic and Classical Period

George Varoufakis*

Department of Chemistry, University of Athens, Greece

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Abstract: A few years ago, the present author had the opportunity to study the iron clamps of the archaic and classical temples. This research led to very interesting results concerning the development of technology applied in making those clamps and what is more its rapid evolution in a very short period. For instance, the technology in making the clamps of Parthenon and those of the Epikourios Apollo differs completely, although the latter was erected by the same engineer, Iktinos. Actually, it is a revolutionary one as compared with that applied in the erection of Parthenon. The paper starts by examining the making of the archaic Trapeza iron clamps and continue with those of the Parthenon and the Epikourios Apollo.

Key words: Iron clamps, archaic temples, classical temples, development in technology, macro & micro examination.

1. Introduction

The archaic temple of Trapeza was erected during the end of the 6th century B.C. somewhere in the north of Peloponnese. Fig. 1 shows a double tee clamp after grinding, polishing and etching with nital 10% (alcoholic solution of nitric acid).

There are two arrows, the one at the left show a dark islet in a brighter framework, while another one exists at the right sight.

The dark islet found to be steel (an alloy of iron and carbon in the shape of Fe_3C in a framework of soft iron). The arrow on the right side shows hot welding by hammering at about 1,200 ^{o}C of two simple tees into one double tee clamp.

Table 2 shows a) the carbon content of the soft iron, and its hardness in HRb and that of the hard steel, and b) the carbon content, of the steel and its hardness always in HRb.

The chemical composition of the iron clamps of Table 2 shows clearly, that foreign impurities are very low, particularly as far as the undesirable S (sulfur) is concerned. It is well known that when the sulfur content is above a certain limit, this may cause splitting of the metal during its shaping at high temperatures. The same composition applies for the Parthenon and the Epikourios Apollo clamps, as well, and leads to the assumption that the iron ores used to produce the iron clamps of all the said ancient temples derived from Laconia-Sparta in Peloponnese; and the critical question is how they know for sure the provenance of the ores.

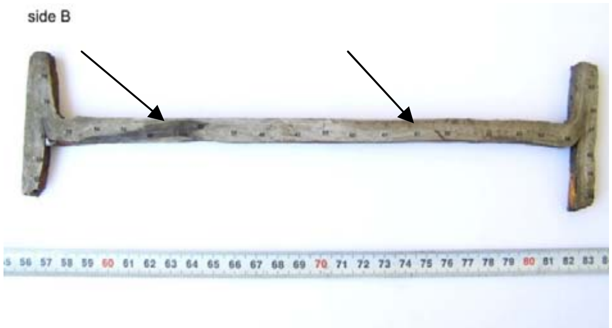
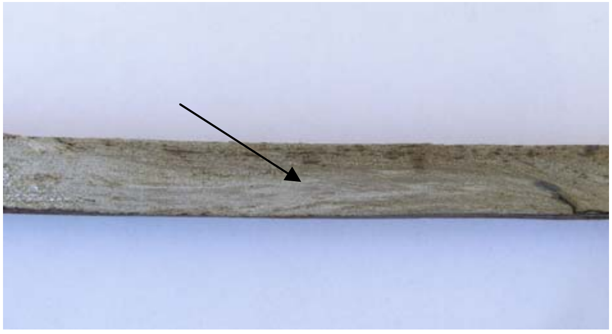


Fig. 1 A double tee clamp from the archaic temple of Trapeza-Peloponnese after polishing and etching with nital 10%.

*Corresponding author: George Varoufakis, Professor, research fields: present and ancient metallurgy and technology. E-mail: georgevaroufakis@yahoo.gr.

(a)



(b)

Fig. 2 A detail profile chart of Fig. 1: (a) it is an islet of steel in a brighter framework of soft iron; (b) the hot welding point (about 1,200 ^{o}C) between two simple tees into one double tee clamp.

The answer is the following. The blast furnaces of the steel company "Halyvourgiki" were producing daily 1,200 tons hot iron (i.e., fluid cast iron), which was then transformed into steel. For this amount of hot metal, about 2,000 tons of iron ores were needed daily to be loaded in the said furnaces. This was the cause, that people living near old or non yet exploited iron mines, dreamed to sell iron ores to Halyvourgiki even just a small part, becoming in this way rich. So, they started bringing to its laboratories bags of iron ores from all parts of Greece. In this way the author is aware of the quality of almost all the existing Greek iron ores. Now, one of the sand bags came from Laconia, near the town of Sparta. The results of their examination were exactly the same just shown in the Table 3. Rich in iron and free from undesirable foreign impurities like sulfur. Therefore, the ores from Laconia Sparta would be more likely used to make the iron clamps of the said ancient temples. It is interesting to note, that modern roads around Sparta used as raw material ancient slag covered by asphalt.

The question, however, is how Spartans were selling rich ores to Athens, their adversary town? The answer is that the Parthenon was erected a few years after the victorious war against the Persian invaders, during which both cities were allies.

2. Climbing a Scaffolding

Figs. 1 and 2 show the south-east part of the temple under repair. The present researcher started to climb the scaffolding feeling safe as far as he was protected by the latter. It is interesting to note, that climbing up, he felt the breathing of the technicians working under the engineers Iktinos and Callikrates, and of the artists under the great sculptor Pheidias.

Suddenly, he found himself at the top of the scaffolding, having a magnificent view of all the city of Athens, although he confessed that he felt a little dizzy, and the city seemed to swirl around him.

3. Metallurgical Studying of the Iron Clamps of the Parthenon

Fig. 4 shows a double iron clamp from the Parthenon. One can note that its middle looks to have a slightly white spot. This is due to the existence of a hot welding between two single tees into one double tee clamp after hammering at a very high temperature of almost 1,200 ^{o}C.

Fig. 4 is a sketch, showing of how the double tee clamps were inserted in the marble blocks, and what is more, how they were protected by lead: (a) This metal

Table 1 Chemical composition of the iron clamps.

	%C	%Mn	%S	%P	%Si	%Ni	%Cr	%Cu	%Pb	HR_b
Iron	0.012	0.045	0.007	0.028	0.062	0.009	0.002	0.007	0.033	56
Steel	0.33	0.0787	0.003	0.025	0.034	0.012	0.003	0.085	0.05	105

Fig. 3 The south east part of the Parthenon under repair some years ago.

Fig. 4 An arrow shows a white spot, which indicates the hot welding point (1,200 ^{o}C) between two simple clamps into one double tee clamp.

was introduced after melting (melting point of lead is 312 ^{o}C) into the marble grooves, where it solidified; (b) the double tee clamp was heated not more than 500 ^{o}C and placed it on top of the solidified lead; and (c) the already solidified lead melted, and the hot iron clamp sunk into the latter covered completely by this protective metal.

4. Macroscopic Examinations of the Ancient Clamps of Parthenon

An effort to examine the macro-structure of the clamps was studied by the researcher. The sample was done by grinding, polishing and etching it (with nital 10%) longitudinally. However, Fig. 6 showed a strange macro-structure, consisting of many obscure layers. This however was due to the hot hammering (at about 1,200 ^{o}C), which distorted its true structure.

That is why, the present researcher asked a technician to cut longitudinally a clamp as shown in the sketch of the Fig. 7.

It is worth noting, that the Parthenon clamps in contrast of those of the archaic Trapeza temple, and those of the Epikourios Apollo, were very large, and therefore it was possible to cut them longitudinally, and examine the interior surface macroscopically. The result is shown in Figs. 8 and 9, which is quite different from the previous one, and actually is the true structure. In the case, however, of the Parthenon, metallurgists at Laurion, 60 km south east of Athens, knew how to produce separately steel and soft iron, and then to weld them together in layers at high temperatures of about 1,200 ^{o}C, as already shown in previous research. The final procedures, however, would be realized by technicians at the workshops of the temple, where they were producing the double tee clamps, according to the dimensions of each groove, into which the clamp would be inserted. All these prove that technology in making them at the said temple was very much more advanced compared with those of the archaic Trapeza temple.

Finally, chemical examinations of the Parthenon clamps proved that iron ores used as raw material in making them were of Laconia provenance.

5. The Iron clamps of Epikourios Apollo

Fig. 11 shows a wonderful ancient temple of Epikourios Apollo, the last work of engineer Iktinos. In contrast to the latter and that of Trapeza, whose

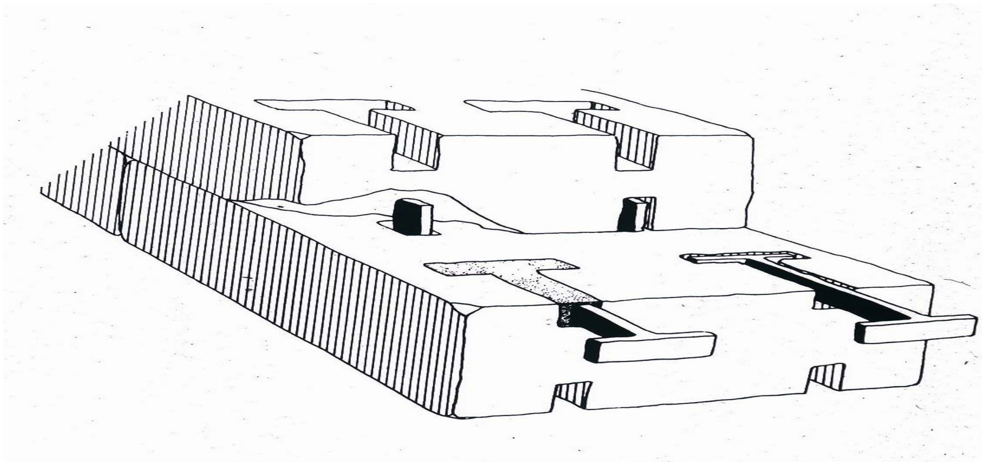


Fig. 5 Impression of the solidified lead covered the clamp, protecting it from corrosion.

Fig. 6 The surface of a side clamp after polishing and etching with nital 10%.

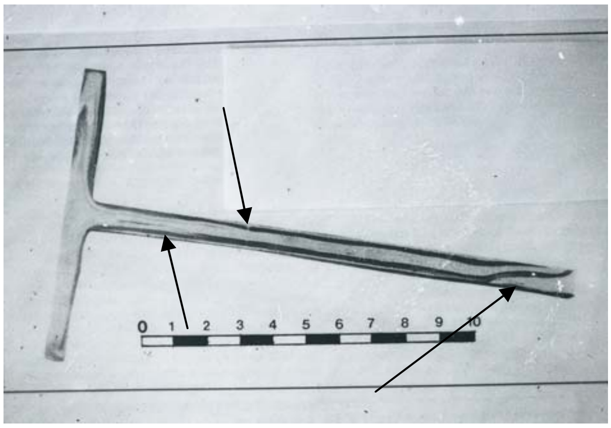


Fig. 8 A simple tee clamp from the Parthenon after polishing and etching with nital.

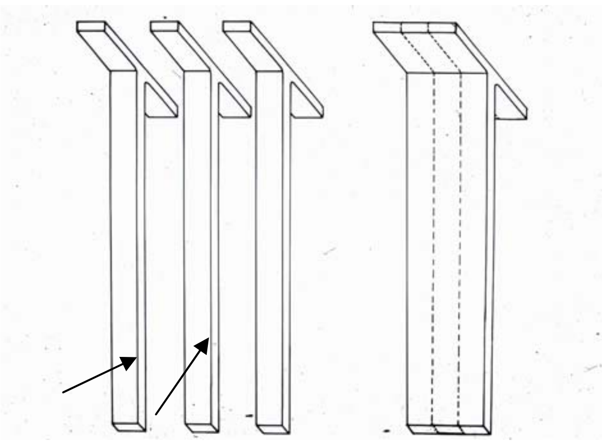


Fig. 7 The arrows show the inner surfaces after the cutting of a large clamp from the Parthenon into three pieces.

Fig. 9 Another simple tee clamp after polishing and etching as above.

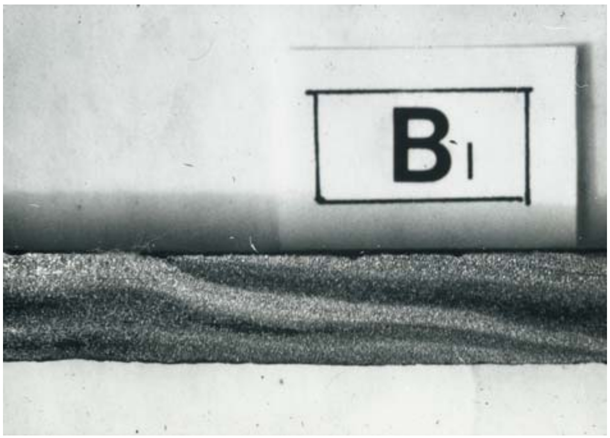


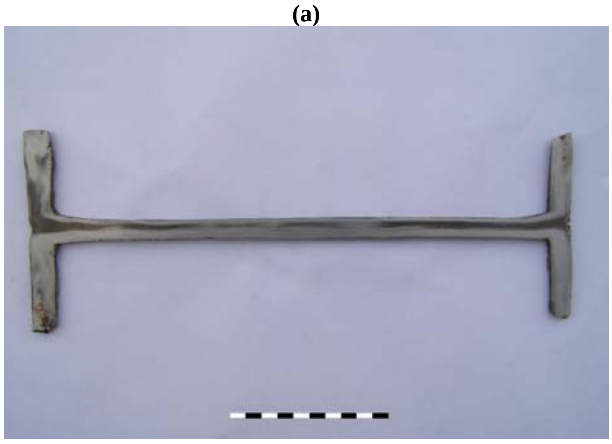
Fig. 10 A detail of a welding point in larger magnification.

Fig. 11 The temple of Epikourios Apollo.

Fig. 12 Hot welding at high temperatures of long iron and casually steel layers, leaving free the ends. The latter were bent in a second stage to produce the tee shape. In other words they avoided the very difficult process of welding two simple tee clamps into one double one.

Fig. 13 A double tee clamp from the temple of Epikourios Apollo, without any welding in the middle.

(a)



(b)

Fig. 14 (a) Shaping of the ends into tee shape; (b) A steel layer almost in the middle was used during shaping.

orientation are east-west, in the case of Epikourios Apollo is north-south. And something else, very important; while the columns of the Parthenon are all of Doric style, in the case of Apollo the external columns of the temple, as shown in Fig. 11 are Doric, while internally there is an extraordinary combination of Ionian and Corinthian columns.

It is also very interesting to mention the revolutionary technology applied in the making of its iron clamps in comparison to those of the archaic temple of Trapeza, and those of the Parthenon for the following reasons:

(1) The iron clamps are of smaller dimensions than those of the Parthenon, and this means the use of less iron; a metal very difficult to produce at those times;

(2) There is no welding point between two simple tees to produce a single double tees clamp at high temperatures (about 1,200 ^{o}C). Instead, they welded together at high temperatures long iron and casually steel layers, leaving free the ends; the latter were bent in a second stage to produce the tee shape. In other words they avoided the very difficult process of welding;

(3) Chemical examination showed again that raw material i.e., iron ores, were of Laconia-Sparta provenance.

In other words, the clamps of the Epikourios Apollo constitute a revolutionary applied technology.

6. Conclusions

On the basis of the metallurgical investigation regarding the making of the iron clamps of the archaic and classical temples, the following interesting results are worth to be mentioned:

(1) The clamps of Trapeza belong, as mentioned, to the archaic period and have the following characteristics: technicians of that period were using iron as produced in the furnace, without any further elaboration to produce simple tees. Therefore, their examination showed to contain a mixture of soft iron and islets of steel. The latter was used in making double tee clamps at high temperatures (1,200 ^{o}C), as already mentioned;

(2) The clamps of Parthenon were of larger dimensions. Technicians were using (a) soft iron in combination with hard steel, which they welded together, always at high temperatures (about 1,200 ^{o}C), and (b) they produced as in the case of the Trapeza clamps, separately two simple tees, welded at high temperatures into one double tee clamp;

(3) The clamps of Epikourios Apollo consists a more developed technology. As already explained they were produced by welding together layers of iron and sometimes of steel into one piece, leaving free their ends, which were finally bent into tees;

(4) Finally, the iron ores used to make all the types of iron clamps were from Laconia-Sparta. This is the only common characteristic of all the examined clamps.

To end the present research work, it is worth mentioning a comment regarding the Greek and Roman technologies: some consider that ancient Greeks created a great civilization in the sectors of philosophy, poetry and art, while the Romans developed technology. It should be stated that that master pieces like those of Parthenon, Epikourios Apollo and other temples, bronze statues, ceramics, jewelries and other masterpieces would had never been created without the application of a high developed technology. In other words art does not exist without technology. For sure, the Romans had developed a more advanced technology, but they did not start from zero. They simply continued to improve greatly the Greek technology, and this is actually a fact, never to be forgotten.

References

[1] George, V. The History of Iron from Homer to Xenophon the Iron Finds and the Ancient Greek Literature with the Eye of a Metallurgist. Athens, 2005.

[2] Ancient Greek Standards. The History and Control of the Materials Which Left Their Mark on *Greek Civilization*. Aelos, Athens 1999.

[3] George, V. *The Iron T-Clamps and Dowels of Parthenon,* Proceeding of the Second Conference in Delphi, 19th-21st Athens, April, 1995.