THE USE OF DIFFERENT JOINING METHODS IN ANCIENT INDIAN STEEL MONUMENTS

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Abstract : In India, the non-rusting iron pillar at Delhi is the most popular ancient monument. But the pillars at Dhar, Mandu, gears of the temple in Puri and Konarak and big cannon pipe at Thanjavur are not well known to most of the people in India. To manufacture such heavy monuments weighing number of tonnes, different joining methods were used like forge welding, soldering, mechanical fixing and joining by shrinkage. The various joining methods will be highlighted with examples of the ancient monuments.

Key Words : Ancient steel monuments, forge welding, soldering, mechanical fixing and fixing by shrinkage

Delivered at SOJOM 2000

INTRODUCTION

In the old Indian poems (Vedas dt.1500 B.C.), it has been mentioned already "iron" from the Sanskrit word "Ayas" [1]. So, in India iron and steel production has an old tradition. At first, steel was used for manufacturing tools and weapons like daggers and swords. Small furnaces with a height of around 1.25M with a diameter of 30-50 cm were used to produce iron and steel. The reduction of iron ores by use of char coal was the metallurgical process. Carbon is the heating and reduction element. Iron ores and charcoal were given in layers in the furnace and after ignition of the coal, air was blast in the furnace by hand or foot-driven bellow. The result of the metallurgical reaction is a "bloom" of steel 10-15 kg in solid condition, because of the low temperature of the charcoal fire (about 1250ºC).

The steel produced has a carbon content of 0.1 - 0.2% and therefore the melting point (~1500ºC) cannot be reached. Such a bloom contains a lot of inclusions and so the next process is forging for cleaning the bloom. The blooms had to be welded together to manufacture the monuments weighing number of tonnes.

FORGE WELDING PROCESS

The forge welding process is explained in the following steps:

- Heating to forging temperature (under solidification line in the Fe-C diagram) and
- Deformation of both parts to get the forge welded joint
- Cooling down to room temperature

To manufacture knives, swords and other tools, the manpower of the blacksmith and impact of his hammer with a weight of 5-10 kg may have been sufficient. The frequency of the impacts can be increased by employing two or three blacksmiths, but it seems to be inadequate to produce monuments like Delhi pillar.

In European countries during the middle ages, water-driven hammers were used with a weight of 1-3 tonnes (See Fig. 1) [2]. Water wheels in those days in India were not known.

Fig. 2 shows another possibility to increase the manpower and the impact energy by means of a "hammer machine". Such a hammer machine can be positioned in the

Fig. 1 : Use of water driven hammers in the 17th century

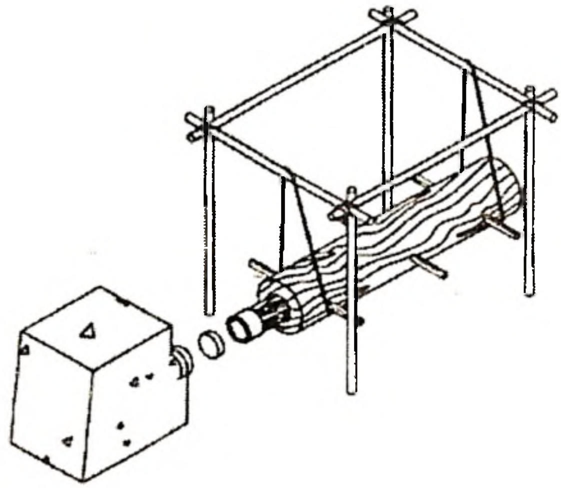

Fig. 2 : Hammer machine

longitudinal axis of a pillar to increase the length of the pillar in the forge welding process or also transverse to the longitudinal axis to forge the pillar round, square or as an octagonal. In such a way, it may be possible to produce such heavy monuments like Delhi pillar with a length of 7.3M, one meter under the earth, and a weight of 6.5 tonnes. Fig. 3 shows the pillar with a lot of visitors. The visitors are trying to close the arms around the pillar and so this part of the pillar is polished every day and in the polished conditions, the blooms and inclusions are visible (see Fig. 4). The Delhi pillar was manufactured during King Chandra Gupta period ~310-375 AD and brought to Delhi in 1052 by King Anang Pal.

Fig. 3 : The Delhi Pillar

Fig. 4 : The polished part of the Delhi pillar with inclusions, borders of the forge welded blooms

Fig. 5a : Top part of the cap of the Delhi pillar (Photo provide by Mr. Balasubramanian, IIT, Kanpur)

Fig. 5b : View from below to the first part of the cap

SOLDERING

Neogi [3] in his book "Copper in ancient India" commented on brass: "Owing to the much earlier discovery of zinc in India, the chemistry of brass was very much understood in India than in Europe..............". With the knowledge about brass and bronze the use of both alloys as soldering metals, especially for joining of steel parts in weapons, was going on. A special application of brass or bronze is demonstrated in the next photo (see Fig. 5a). The photo shows that the cap of the Delhi pillar was manufactured from single parts of plates, flanges and forged rings. The top plates might have been joined together by soldering. These joints are not faultless. There are many holes. If you look at the first part cap of the pillar, it is visible that the gap between the body of the pillar and wonderfully styled first part is closed by a metal with another colour (see Fig. 5b). The last example for joining of huge parts of steel by soldering is shown in Fig.6. This "crown" is made from steel and the dimensions are 570mm height, 340mm dia of the rings at the bottom. All single parts are joined by filling up the inner volume with a copper-tin alloy with 67% Cu and 32% Zn. The chemical composition is comparable with DIN 17666 with 70% Cu and 28% Zn.

MECHANICAL FIXING

The non-rusting pillar near Lat Masjid at Dhar is seen in Fig. 7. The pillar has been described in detail by Cousens [4]. The three pieces have a full length of 13.22 M and a calculated weight of 7.3 tonnes. First part has a length of 7.37M and is nearly a square of 260 x 270 mm^2, and the second part is 3.56M length and has a size of 260 x 270 mm^2 and it goes over in a length of 2.80M in an octagonal size, ending with a cone, 140 mm length and a diameter of ~ 240mm at the end. The last part of the pillar is 2.29M length and is octagonal beginning with a cone of 210mm length and also with a diameter of ~ 240mm.

Investigations revealed clearly that the first and second part of the pillar have been joined together during manufacturing by forge welding process. With the conical end of the second part of the pillar and conical beginning of the third part of the pillar, it is clear that these both parts had not been joined by forge welding process. A sketch gives a possible solution for the joint (see Fig. 8). Both parts might have been joined mechanically by a special forged ring. Cousens [4] has described that the pillar was fixed into a big stone. But when we see the height and the mechanically fixed second and third part, it is clear that the pillar has to

Fig. 6 : "crown" laying in the museum of the Red Fort in Dhar

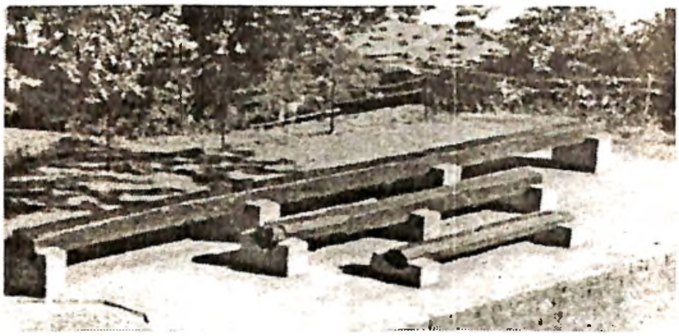

Fig. 7 : The non-rusting Iron Pillar at Dhar

be fixed in upright position with the help of cables, ropes or strong wires to hold the pillar.

In [5], there is a proposal given for the reconstruction of the Dhar pillar. In a museum near Mandu, a big steel anchor of about 430 Kg (see Fig. 9) was found. It is considered that the upper surface of the last part of the octagon is a brittle fractured surface (see Fig.10). In the Red Fort of Dhar the possible "crown" was found (see Fig. 6). The recommendation shows the pillar fixed into a stone, and also fixed with cables, ropes to keep it in upright position, holding by steel anchors, joined by a forged ring in a height of about 11m, is missing the last part of the octagon and a possible crown (see Fig. 5 and 6). When we fix the octagon together with the crown to the pillar for final reconstruction, the

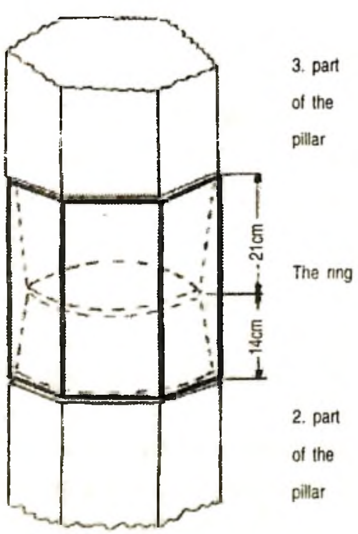

Fig. 8 : The ring to join the second and third part of the pillar

Fig. 9 : The anchor at Mandu

Fig. 10 : Brittle fractured surface on the top end of the Dhar pillar

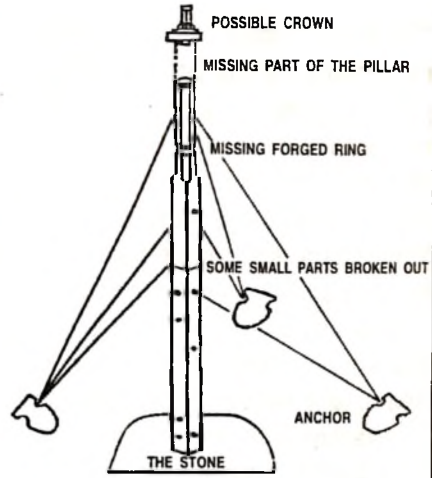

Fig. 11 : Proposal for the reconstruction of the Dhar Pillar

pillar may have got a height of about 15m.

JOINING BY SHRINKAGE

Fig. 12 shows the big cannon pipe at Thanjavur [6]. The cannon pipe has a length of 7.5M, the outside diameter is 1.04M and the inside diameter is 630mm. There are 39 strips inside the pipe, having a thickness of 15mm and 50mm of breadth. From the front view, it looks that the pipe is manufactured in three layers of rings, each with a thickness of about 50mm. The weight can be calculated to 30 tonnes. Also the volume of the gun powder used in the cannon pipe can be calculated to 155 litres. From the outside, it is visible that the pipe was manufactured from individual rings of 70-90mm width. The three layers of rings were heated to a temperature of about 1000ºC. Then we can calculate the expansion of the second layer to:

$Dd = d \times Dt \times \mu Fe$

d : inner diameter

Dt : temperature difference

μFe : expansion factor for Fe

$= 730 \times 1000 \times 12 \times 10^{-6} = 8.76mm$

It means that the rings must have been forged exactly with the inner diameter of < /=9mm to come to a shrinkage condition and to close the gaps between the rings of the first layer of rings by the second layer and to close the gaps between the rings of the second layer by the rings of the third layer.

The question of handling and transportation of a pipe with weight of 30 tonnes in the olden days is still to be answered.

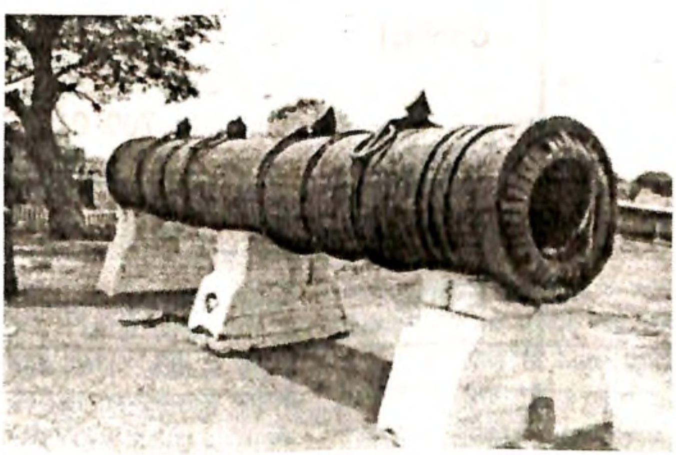

Fig. 12 : The big cannon pipe at Thanjavur

CONCLUSIONS

The forge welding of huge ancient monuments like the Delhi and Dhar pillar developed an idea to increase the manpower with the help of hammer machine and to increase the impact energy for forge welding. With such a machine the pillars and beams were forge welded in horizontal position. Bronze and brass were well known in ancient times in India and usually were used for soldering of weapons from steel. Bigger parts from steel like the top head of the Delhi pillar may also be joined by soldering. As an example, the chemical position of a soldered crown was found as 67% Cu and 32% Zn, like in DIN 17666. For mechanical fixing, a huge iron pillar at Dhar was held together by a forged steel ring and ropes, cables with heavy anchors made by steel to hold the biggest iron pillar in upright position. The cannon pipe at Thanjavur with a length of 7.50m and weight of 30 tonnes was manufactured from single rings in 3 layers by shrinkage. All these examples show that the blacksmiths were highly skilled in metallurgical processes as well as in the field of joining technology by use of different joining methods.

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