Archives of Materials Science and Engineering

Volume 38
Issue 2
August 2009
Pages 112-117

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

# Effect of flash butt welding parameters on weld quality of mooring chain

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Received 12.03.2009; published in revised form 01.08.2009

## ABSTRACT

**Purpose:** The effects of flash butt welding parameters on mechanical properties were explored for mooring chain for offshore structure.

**Design/methodology/approach:** Through the tensile strength, impact energy, hardness of weld, macrosection, microstructure and waveform analysis of the flash butt weld, following the change of the flash mode, flash length, upset mode, and upset length which are the parameters of the flash butt welding, the weld quality has been assessed.

**Findings:** It is confirmed that even if the mechanical properties of the weld are satisfied through experiments, a weld defect may exist, and in case of using force mode in upset process, the mechanical characteristics of the weld is superior to position mode.

**Research limitations/implications:** The optimal welding condition presented in this study may be changed in accordance with the chemical composition of the material, size of mooring chain.

**Practical implications:** In this study, the suitable welding conditions were presented for securing a good weld quality of the high strength steel mooring chain for the offshore structure.

**Originality/value:** Through this study, the correlation between the weld parameters and the weld quality in the flash butt welding was confirmed. Though the weld quality assessment, flash butt welding condition of the ø84 mm mooring chain for the offshore structure was presented.

**Keywords:** Welding; Mooring chain; Flash butt welding; Flash; Upset

**Reference to this paper should be given in the following way:**

D.C. Kim, W.J. So, M.J. Kang, Effect of flash butt welding parameters on weld quality of mooring chain, Archives of Materials Science and Engineering 38/2 (2009) 112-117.

MATERIALS MANUFACTURING AND PROCESSING

## 1. Introduction

Recently, due to the exhaustion of oil resources, the exploration of oil well in the deep sea, the extremely cold regions has been increased. Thus the requirement of the strength and impact energy of the mooring chain used for fixing ships and offshore structures has been intensified [1-5]. The length of mooring chain is hundreds of meters to 1.7 kilometres, and the cross section area of the mooring chain to be welded is considerably large.

Flash butt welding is one of the resistance welding process employed to join metals. In flash butt welding process, the ends of the piece to be welded are connected to the secondary circuit of a transformer, while one piece is held firmly by a clamping device attached to a stationary platen, the other piece is clamped to a movable platen. The surfaces to be welded are allowed to touch when heavy currents pass through the peaks or asperities of the edges providing resistive heat to the edges. These asperities start melting and, at greater velocities, the molten bridges are broken and thrown off as flash particles from joint. This cycle of the formation and collapse of bridges goes on as the movable platen advances. When the conductive heat was sufficiently heated the metal behind the faying surfaces on either side to ensure adequate plasticity, the flashing current is stopped and surfaces are butted against each other at greater force. This action ensures that the molten metal oxides and other impurities are extruded out of the surfaces to be joined and satisfactory welding takes place.

It has advantages that the large cross sectioned shape materials can be welded in a short time, the preparation cleaning of the interfaces are not required, adequate weld strength.

Flash butt welding is widely employed in the automotive, air craft, and several other engineering industries. Some examples of its use on wheel rims for automobiles, long welded rails, etc. In the case of mooring chain manufacturing, it is often the best and sometimes the only possible method [6-10].

In this study, the change of mechanical properties in accordance with the variation of the welding process parameters has been examined in the flash butt welding of the ø84 mm mooring chain.

## 2. Experiments

A typical flash butt welding machine consists of four major parts:

1. The machine bed, to which is attached the fixed platen with clamping assembly, and a set of insulated ways to support the movable platen;
2. The movable platen with clamping assembly, which is mounted on the electrically insulted ways;
3. A mean for controlling the motion of the movable problem;
4. The welding transformer [11].

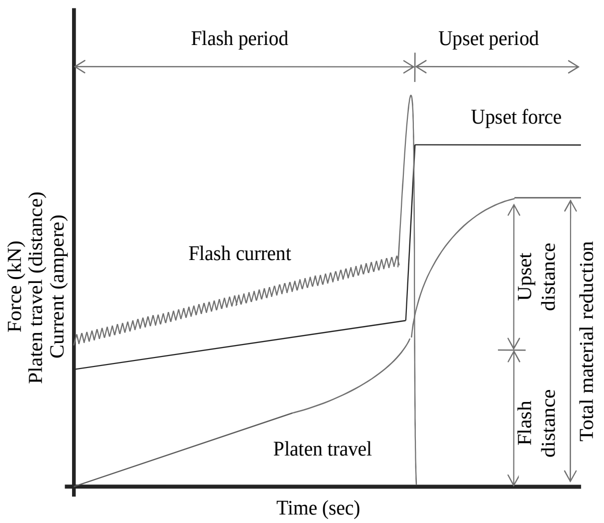



Fig. 1. Schematic of typical flash butt welding process

The experiment was carried out using the ESAB flash butt welding machine. As the welding process parameters, the flash mode, flash length, flash current, upset mode, and upset length were used.

Fig. 1 shows the schematic of typical flash butt welding process parameters such as flash current, platen travel position, upset force. The platen travel is continuous starting at the time of flashing and progressing until upset. At upset period the platens are rapidly squeezed together for upsetting, the current may be immediately terminated.

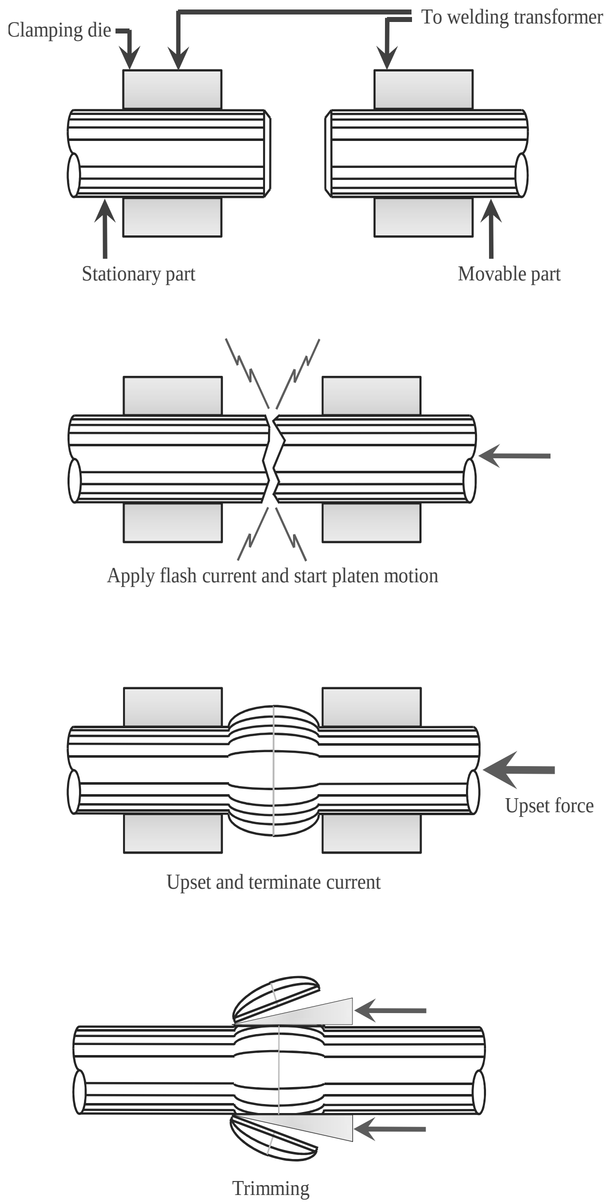



Fig. 2. Basic steps in flash butt welding

Fig. 2 shows the basic steps in flash butt welding. The material being joined is clamped rigidly in the dies, and the specimens are separated by a suitable air gap. Then the movable platen is advanced slowly until contact is made between two or more small protuberances on the opposing interfaces, thus providing a current path. The motion of the movable platen is continued, at a constantly accelerating rate producing many short-circuits randomly located over the opposing interfaces, each of which is terminated by rupture of the bridge as the molten metal produced is expelled. This portion of the process is known as the flashing period, its objective being the establishment of a suitable temperature distribution in the work to assure proper forging action during the subsequent upset period of the cycle.

After flashing, the movable platen is accelerated rapidly by automatic application of an axial force of suitable magnitude causing intimate contact between the interfaces to be achieved rapidly and completely. This portion of the operation is known as the upset period. After terminating upset, the clamps are opened and the welded assembly is removed from the machine. The solidified metal expelled from the interface during welding is removed by trimming machine [11].

The platen travels in constant speed (linear flashing pattern) in proportion to flashing current in current mode of flashing period.

The platen travels in accelerated speed (parabolic flashing pattern) in accelerating mode of flashing period.

The flash butt welding condition used for the experiment was indicated at Table 1.

For flash 1, flashing mode was current mode. For flash 2, test No.1 and No.4 used accelerating mode, and the other tests used current mode. Two modes for upsetting were position mode and force mode. For the position mode, the platen travels up to upset length. For the force mode, the platen travels up to upset force. Position mode was used for test No.1~ No.5, force mode was used for test No.6~ No.10 [12-13].

Table 2 shows the chemical composition of the ø84 mm mooring chain used in this study.

After polishing the weld specimen and etching it with the 4% Nital, the microstructure of weld was observed, and in order to assess the mechanical properties of the weld, the tensile strength test and the impact test were performed. The temperature of the Charpy V-notch impact test was -20°C. The average of three specimens for absorbed energy was calculated.

Table 3 shows the requirements of the base metal and weld of the ø84 mm mooring chain. Although the tensile strength requirement of the weld for the mooring chain is not determined, it was compared with the base metal requirement (87.7 $kgf/mm^2$).

Table 1.
Flash butt welding conditions

| Test No. | Flash 1 | | Flash 2 | | | | Upset | | Weld time (sec) |
|---|---|---|---|---|---|---|---|---|---|
| | Length (mm) | Current (%) | Length (mm) | | Length (mm) | Current (%) | Length (mm) | | |
| 1 | 8 | 63 | 12 | - | 0.4 | 0.2 | 10 | - | - |
| 2 | 8 | 63 | 20 | 70 | - | - | 10 | - | 46 |
| 3 | 8 | 65 | 12 | 67 | - | - | 16 | - | 42 |
| 4 | 10 | 60 | 10 | - | 0.4 | 0.04 | 10 | - | 46 |
| 5 | 15 | 60 | 15 | 70 | - | - | 10 | - | 47 |
| 6 | 2 | 65 | 18 | 70 | - | - | - | 90 | 47 |
| 7 | 2 | 65 | 18 | 65 | - | - | - | 80 | 53 |
| 8 | 3 | 55 | 17 | 75 | - | - | - | 90 | 52 |
| 9 | 4 | 55 | 16 | 70 | - | - | - | 80 | 65 |
| 10 | 4 | 60 | 16 | 65 | - | - | - | 90 | 55 |

| Test No. | Flash 1 | | Flash 2 | | | | Upset | | Weld time (sec) |
|---|---|---|---|---|---|---|---|---|---|
| | Length (mm) | Current (%) | Length (mm) | Length (mm) | Current (%) | Length (mm) | Length (mm) | Current (%) | |
| 1 | 8 | 63 | 12 | - | 0.4 | 0.2 | 10 | - | - |
| 2 | 8 | 63 | 20 | 70 | - | - | 10 | - | 46 |
| 3 | 8 | 65 | 12 | 67 | - | - | 16 | - | 42 |
| 4 | 10 | 60 | 10 | - | 0.4 | 0.04 | 10 | - | 46 |
| 5 | 15 | 60 | 15 | 70 | - | - | 10 | - | 47 |
| 6 | 2 | 65 | 18 | 70 | - | - | - | 90 | 47 |
| 7 | 2 | 65 | 18 | 65 | - | - | - | 80 | 53 |
| 8 | 3 | 55 | 17 | 75 | - | - | - | 90 | 52 |
| 9 | 4 | 55 | 16 | 70 | - | - | - | 80 | 65 |
| 10 | 4 | 60 | 16 | 65 | - | - | - | 90 | 55 |

Table 2.
Chemical composition of mooring chain material (weight, %)

| C | Si | Mn | P | S | Ni | Cr | Mo | Nb | Cu |
|---|---|---|---|---|---|---|---|---|---|
| 0.23 | 0.3 | 1.5 | 0.03 | 0.02 | 0.6 | 1.0 | 0.4 | 0.004 | 0.2 |

Table 3.
Requirements of base metal and weld

| | Tensile strength ($kgf/mm^2$) | Yield strength ($kgf/mm^2$) | Elongation (%) | Reduction of area (%) | V-notch energy (J) |
|---|---|---|---|---|---|
| Base metal | 87.7 | 59.2 | 12 | 50 | 50 at -20°C |
| Weld | - | - | - | - | 36 at -20°C |

## 3. Result and discussion

### 3.1. Tensile strength test

Fig. 3 shows the tensile test result of the weld. The results of the test No. 2, 3, 4, 5, 6, 7, 8, 9, and 10 satisfy the tensile strength of the base metal requirement.

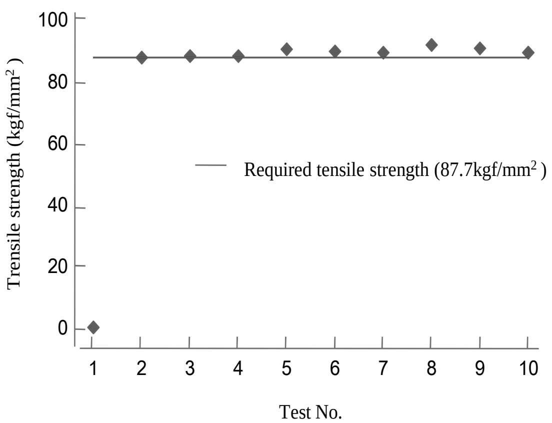



Fig. 3. Tensile strength test result

In case of test No. 1, the welding was stopped because the acceleration of the flash 2 was too large. It was confirmed that the mechanical characteristic of the force mode was superior to the position mode. (position mode 88.6 $kgf/mm^2$, force mode 90.2 $kgf/mm^2$ in average).

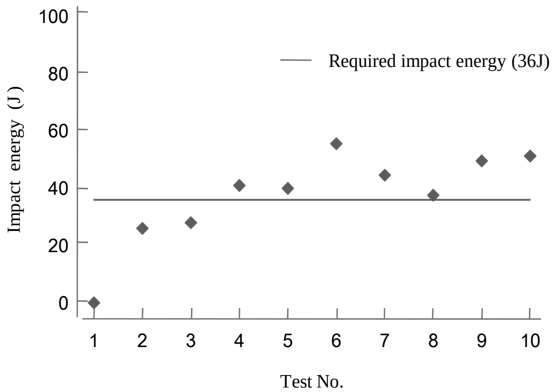



Fig. 4. Impact test result

### 3.2. Impact test

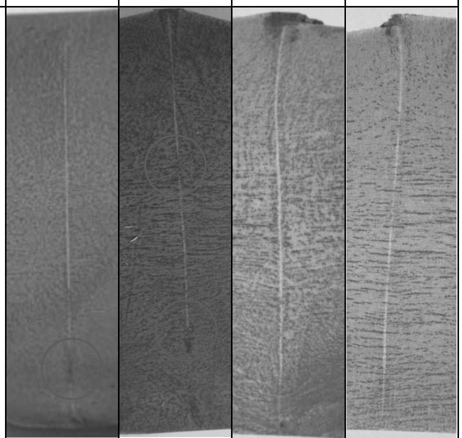
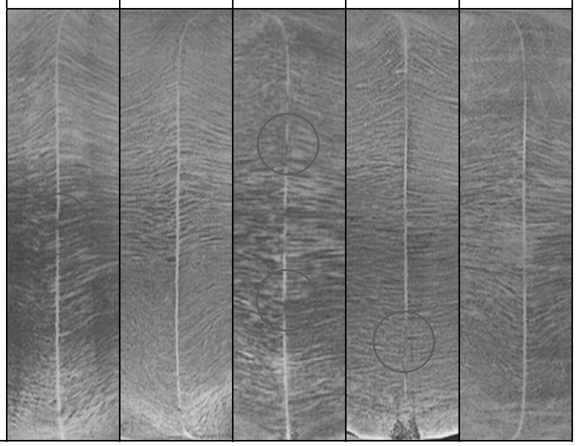
Fig. 4 shows the impact test result of the weld. The requirement of the weld of the mooring chain is 36 J in average. The results of the test No. 4, 5, 6, 7, 8, 9, and 10 satisfy the impact energy requirement. It was confirmed that the mechanical characteristic of the force mode was superior to the position mode (position mode 33.8 J, force mode 47.7 J in average).

### 3.3. Macrosection test and microstructure

Table 4 shows the macrosection of the weld. In the weld, the white line, a decarburized layer, is formed.

This is shown because the carbon of the base metal was diffused to the molten part in the process of flashing and discharged outward in the process of upsetting, and the base metal with relatively little carbon formed the weld line [11,14]. In the weld centre line of test No. 2, 3, 6, 8, and 9, the black line exists. To assess the quality of the black line and white line the microstructure was investigated.

Table 4.
Macrosection of the flash butt weld

| | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 |
|---|---|---|---|---|---|
| Position mode | No data |  | | | |
| | Test 6 | Test 7 | Test 8 | Test 9 | Test 10 |
| Force mode |  | | | | |

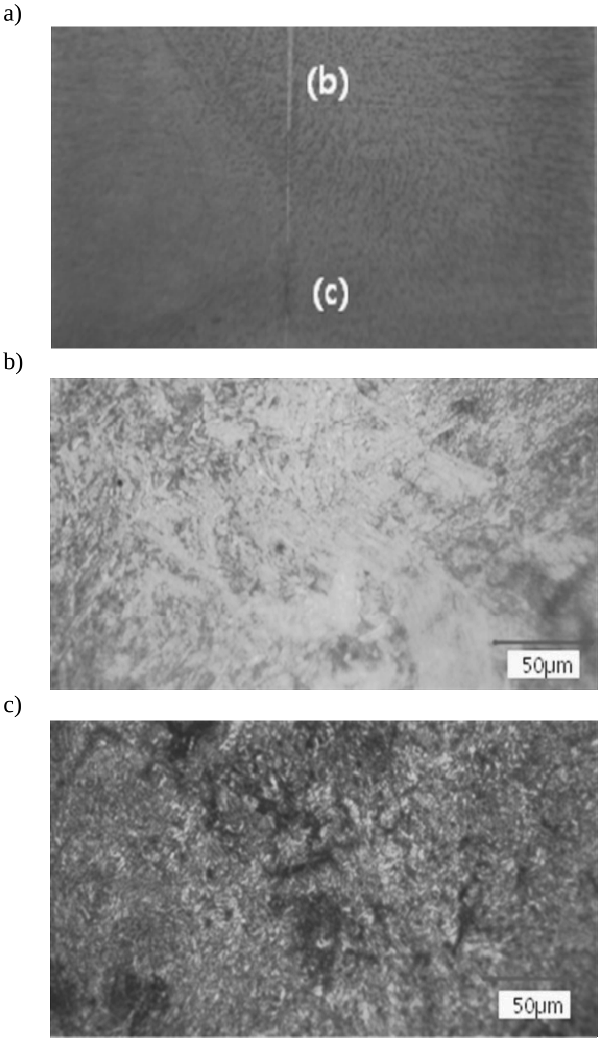



Fig. 5. Macrosection and microstructure of test No. 8: a) macrosection of the weld, b) microstructure of the white line (x50), c) microstructure of the black line (x50)

Fig. 5 shows the weld centre line of test No. 8. Although a good formation is shown in the white line (a), it is confirmed that in the black line (b), there are many defects. It is estimated that the oxide generated in the flash process could not be ejected but remained through the upset process.

Although the requirements of tensile strength and impact energy were satisfied at the test No. 6, 8, and 9, macrosection test shows the weld defects in weld centre line. By assessing the welding quality of each condition through the tensile test, impact test and macrosection test, it was confirmed that the test No. 4, 5, 7, and 10 satisfied all the requirements of the weld and no defect.

## 3.4. Hardness test

Fig. 6 shows the micro Vickers hardness test result. The black diamond-shaped areas are Vickers hardness indentations. The distance between the indentation of right and left is 0.15 mm, top and bottom is 0.1 mm. Test load was 0.5 kgf.

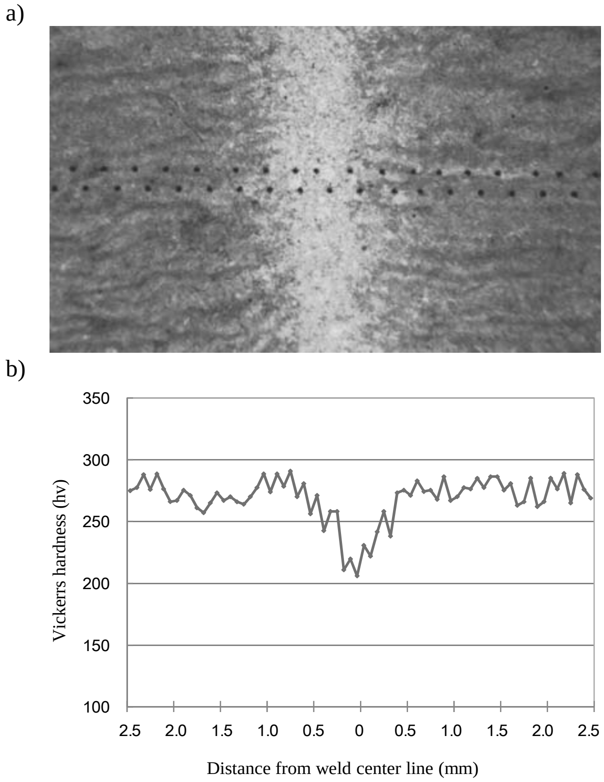



Fig. 6. Micro Vickers hardness test result: a) microstructure of the weld, b) hardness test result

It is shown that the hardness is lower in weld centre line because the carbon of the base metal was diffused to the molten part in the process of flashing and discharged outward in the process of upsetting, and the weld line with relatively little carbon formed the weld line [11,14].

## 3.5. Waveform analysis

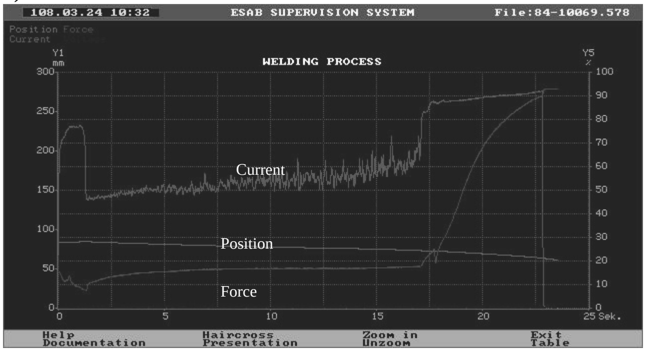
Fig. 7 shows waveform of the flash butt welding current, force, and position.

In Fig. 7 (a), welding was stopped because the acceleration of the flash 2 period was too large. For this, weld interfaces stick together. Therefore it is recommended when using acceleration mode in flash period, the acceleration has to be set under 0.2 mm/s$^2$.

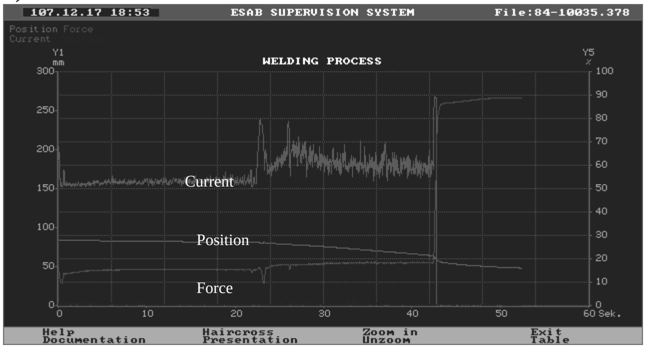
In Fig. 7 (b), flash current of flash 1 and flash 2 are big different (flash 1: 55%, flash 2: 75%), flash current increases rapidly and it causes craters in weld interfaces. Thereby entrapments of oxides at the weld interface occur (see Table 3. test No. 8).

Fig. 7 (c) shows the desired waveform of flash butt welding (test No 5). Flash 1 and flash 2 current are smoothly connected until upset and result in good weld quality.

a)




b)




c)

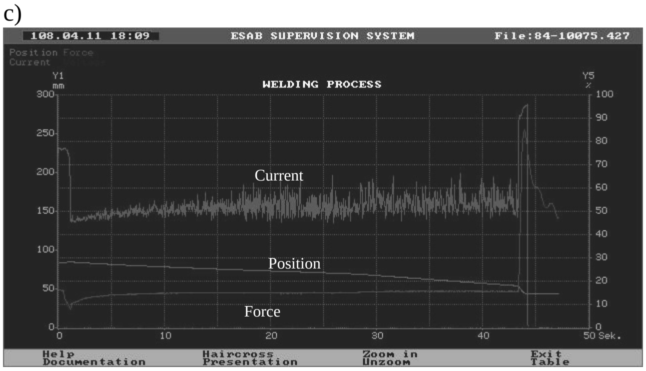



Fig. 7. Welding parameter waveforms of the flash butt welding: a) waveform of the test No 1, b) waveform of the test No 8, c) waveform of the test No 5

## 4. Conclusions

1. It is confirmed that if the force mode is used in the upset process, the mechanical properties are superior to the position mode. (tensile strength increased 1.6kgf/mm$^2$, impact energy increased 14.1 J in average).
2. Although the requirements of tensile strength and impact energy were satisfied, the weld defects existence was confirmed from macrosection test. (test No 6, 8, and 9).
3. By assessing the welding quality of each condition through the tensile test, impact test and macrosection test, the welding condition showing good welding quality can be decided.
4. Defects on the black line are seemed that oxide formed in the flashing section was not discharged but remained through the upset process with small upset rate.
5. From the welding parameter analysis, it is important to make smoothly connected welding current waveform in flash process.

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