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Automatic Control of Arc Welding (Report IV) †
——Detection of Cold Lapping——

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Abstract

On the so called cold lapping phenomenon which is caused by excessive heat input, the welding condition, the weld result and the mechanism are discussed. The optical method to sense this phenomenon is described.

1. Introduction

It has been claimed that the penetration depth of the work piece in arc welding is proportional to n th power of arc current(I^n) and inverse of m th power of welding speed(v^{-m}).The empirical equations on the basis of it have been proposed. Almost all of these equations are, however, obtained by "bead-on-plate experiments".

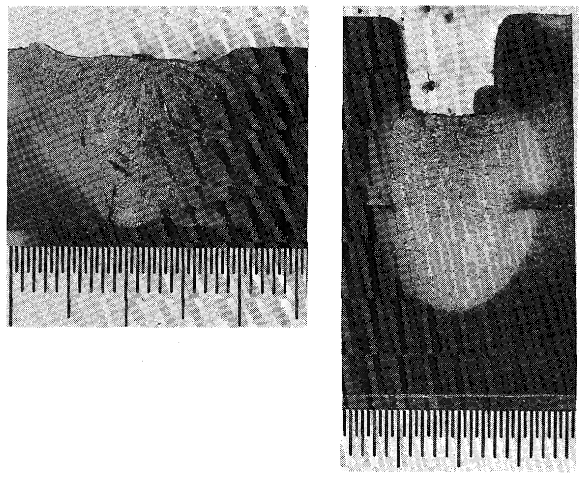
The phenomenon is not so simple at the welding of the work piece with joint edge preparation. For example, in case heat input (per unit weld length) exceeds a certain limit, the penetration depth decreases unexpectedly when arc current increases or welding speed decreases. The phenomenon as it is called cold lapping belongs to this category. This occurs when molten metal flows out beyond the arc generating point due to excessive heat input and excessive filler metal supply, as the result, the energy of the welding arc is not supplied to the unfused material directly.

The limit of welding condition that induces cold lapping depends on the configuration of the edge preparation, i.e., groove angle, groove depth, groove width, etc., therefore, monitoring of the welding process by any means is needed when weld is made on the edge prepared work with considerable large heat input.

2. Weld under excessive heat input condition

When the heat input by arc and feeding rate of filler wire per unit weld length becomes excessive for given edge preparation, the bottom part of the work which affects the penetration depth strongly is not fused sufficiently.

The typical example is shown in Fig.1(a), where the weld experiment was made at arc current 400 (A), (arc voltage 34 (V)), welding speed 3 1/3 (mm/sec) and groove width in edge preparation 5 (mm), and the plate of 15 (mm) in its thickness is almost filled up in one pass, but no penetration of the backing plate (it can not be seen in the photograph) is seen, the side wall of the



(a) (b)

Fig. 1 Macro cross section of weld result.
(a) Excessive heat input weld.
(b) Not so excessive heat input weld.

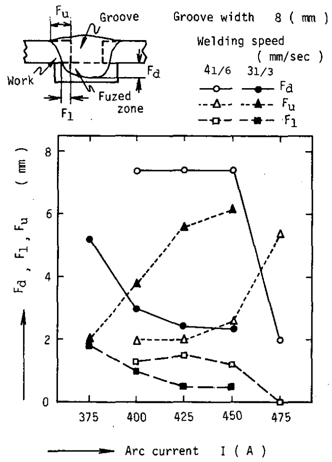


Fig. 2 Weld result under excessive heat input. -- Definition of F_d, F_l, F_u and relation among arc current and these values.

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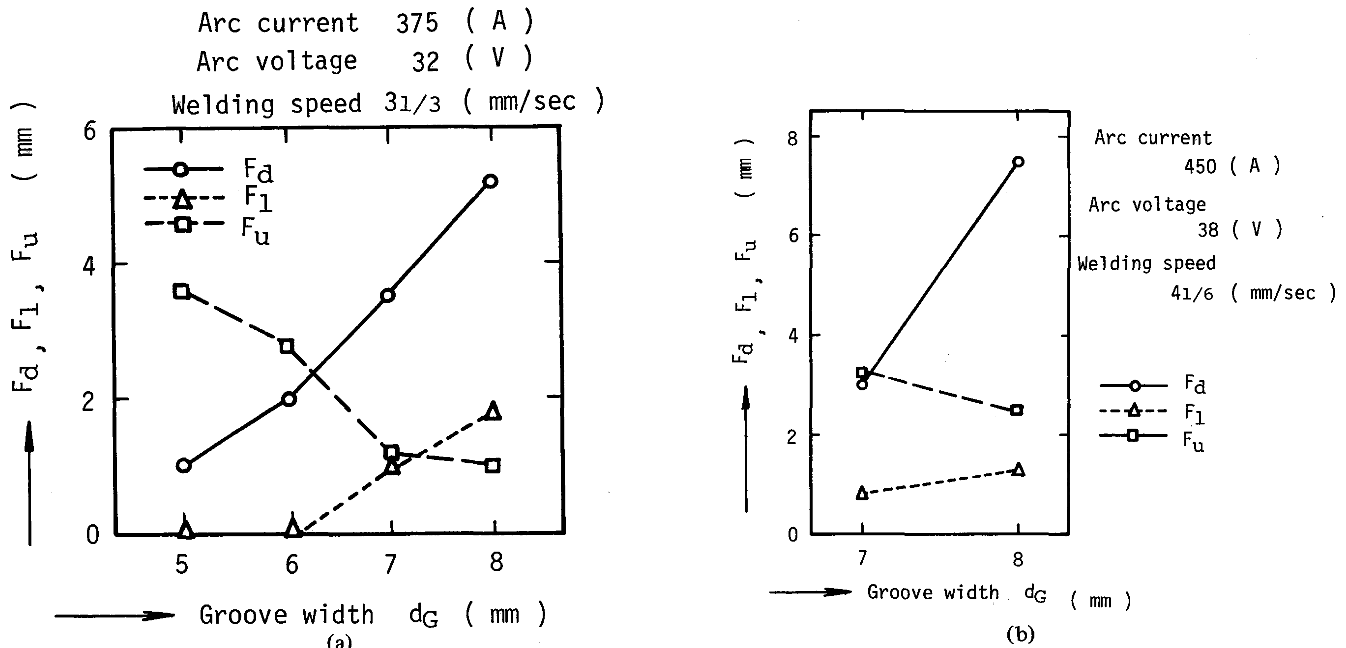

Fig. 3 Weld result under excexxive heat input. --Relation among F_d, F_l, F_u and groove width.

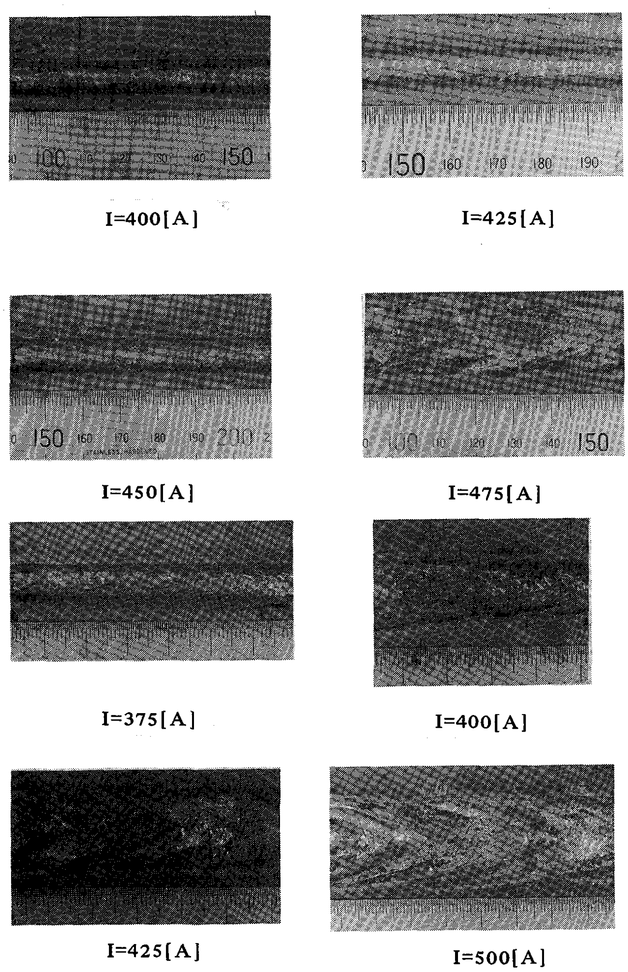

Fig. 4 Surface view of weld bead.
(a) Welding speed 4 1/6 (mm/sec)
Groove width 8 (mm)
(b) Welding speed 3 1/3 (mm/sec)
Groove widyh 8 (mm)

groove is not also fused. In the example of Fig.1(b), the weld was made at welding speed 4¼ (mm/sec), groove width 8 (mm) under the same arc current as the previous example, the backing plate and the side wall of the groove are sufficiently fused owing to increases in the welding speed by 25 (%), in the groove width by 60 (%).

The example for the welding condition of excessive heat input is shown in next. Figure 2 shows the dependency of the penetration depth F_d, the bead width at the bottom of the work F_l and the maximum bead width F_u, which are illustrated and defined in the figure, on the value of arc current, where F_d decreases rapidly and F_l approaches to zero as the arc current, i.e., the heat input, exceeds a certain value, while F_u increases on the contrary. The values F_d, F_l and F_u varies·with the configuration of the edge preparation. This fact is shown in Fig.3 (a) and (b), in which the decrease of F_d,F_l and the increase of F_u, so to say, the lack of fusion occurs as the groove width decreases, even if the weld is made under the same condition. (arc current 375 (A), arc voltage 32 (V) and welding speed 2 1/3 (mm/sec) in (a) and arc current 450 (A), arc voltage 38 (V) and welding speed 4 1/6 (mm/sec) in (b)). The weld bead of the lack of fusion has characteristic feature on its surface view. A series of photographes shown in Fig. 4 (a) and (b) corresponds to the weld result made under the same condition described in Fig.2 respectively. It is natural that the surface bead width spreads as F_u increases, further more, the rough ripples appears on it corresponding to the lack of fusion at the bottom part of the work and their interval increases according as the extent of the defect. This can be seen remarkably in Fig.5, which corresponds to Fig.3 (a).

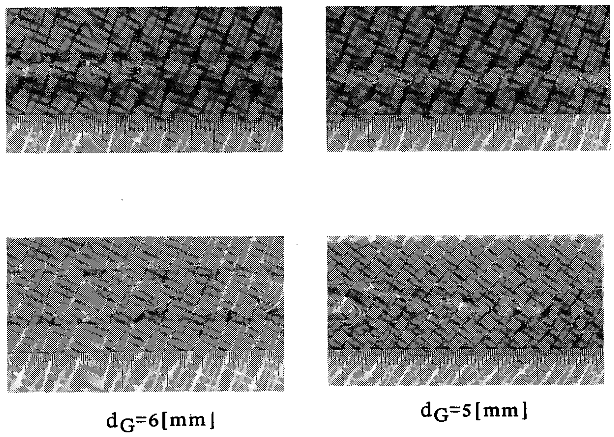

Fig. 5 Surface view of weld bead.
Arc curremt 375 (A)
Welding speed 3 1/3 (mm/sec)

3. Sensing for excessive heat input

The flowing behavior of molten metal can be detected by the same method as previously reported.(1) Another block diagram of the sensing system is shown in Fig.6. The sensing becomes more flexible with this sensor, because it can possess nonlinear characteristics by setting attenuators (potentiometers) arbitrarily. An example of the output signal from the sensor during arc welding is shown in Fig.7. The upper graph of the figure corresponds to the slightly over heating welding process and lack of fusion doesn't occur yet, the lower one corresponds to the state in lack of fusion and the surface of the molten pool moves upward and downward with ultra low frequency (0.2 – 0.02 (HZ)) and large amplitude.

The mechanism which occurs this up and down motion can be explained as follows. The surface of the molten pool swells and its inner static pressure increases gradually as the volume of the molten metal at the back of arc increases owing to excess heat input and excess feeding of filler wire. The molten metal flows out against the force which draws it backward (this force is caused by the difference of the surface tension of molten metal due to temperature gradient in the molten metal, etc.), gets beyond the arc generating point when the inner pressure exceeds a certain threshold value and prevents the arc energy from being supplied to the unfused weld material directly.

The above described lack of fusion phenomenon occurs as the result. The inner pressure decreases immediately after the molten metal flows out and increasing the volume of the molten metal begins again. This process is repeated, the up and down motion of the weld pool is induced and the weld bead with rough ripples is formed consequently as shown previously.

The cold lapping phenomenon can be sensed by perceiving the ultra low frequency vibration of the output signal from the sensor. The period of this ultra low frequency T_{period} vs. the interval of the ripples forming on the bead surface d_{ripple} (defined in the figure) is shown in Fig.8. The linear relation is recognized between them as is seen in this figure. The solid line in the figure corresponds to the equation in which the product of T_{period} and the welding speed v (

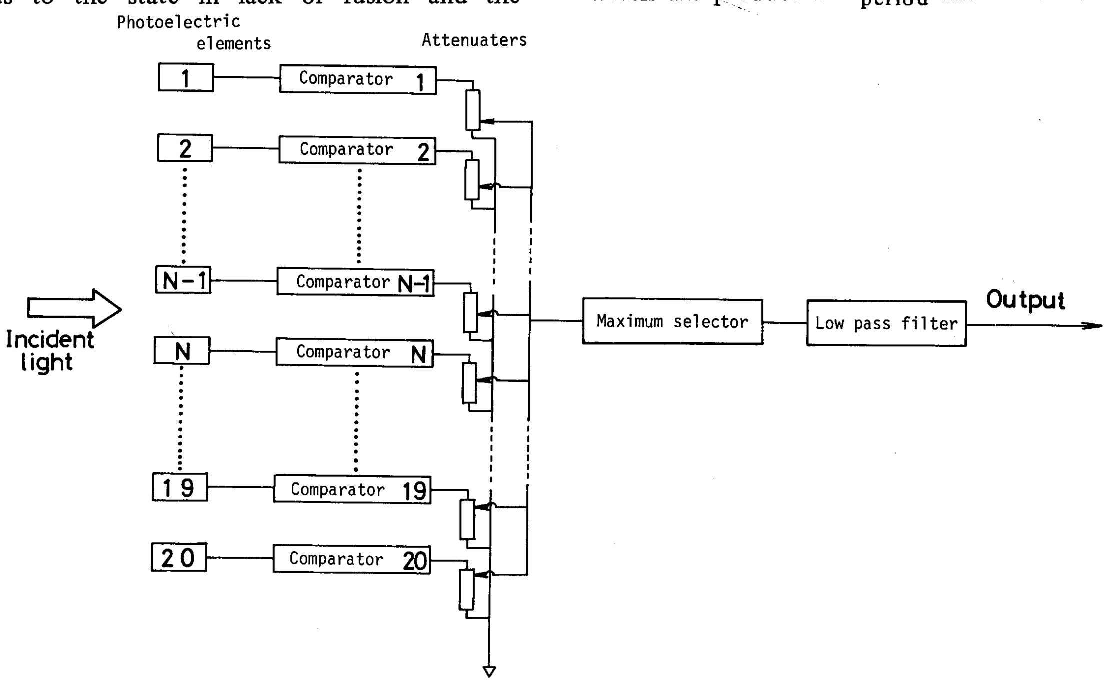

Fig. 6 Block diagram of molten pool posiiton sensor.

=3 1/3 (mm/sec); constant in this experiment) is equalled to the interval of the ripples d_{ripple}.

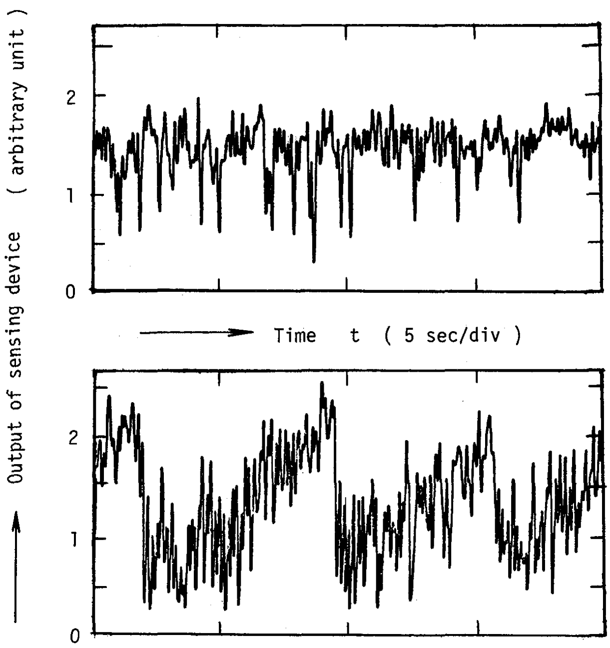

Fig. 7 Cold lapping sensing signal.

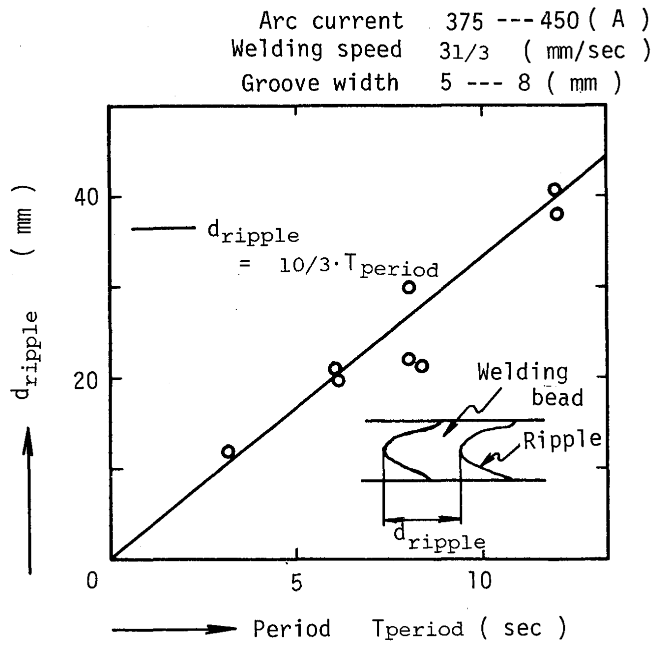

Fig. 8 Relation between ultra low frequency period of cold lapping sensing signal and ripple of weld bead.

4. Conclusion

1) The cold lapping phenomenon generates and the lack of fusion occurs if heat input from arc and feeding rate of filler wire are too exessive for the given edge prepared work.
2) The molten metal in the weld pool moves upward and downward with large amplitude and ultra low frequency (0.2 – 0.02 (HZ)) when the cold lapping occurs.
3) The up and down motion can be sensed with the optical method from the back of the welding arc on utilizing the arc emitting light.
4) The rough ripples are formed on the surface of the bead when the cold lapping occurs.

Reference

1) Y.Arata and K.Inoue : "Automatic Control of Arc Welding by Mon itoring Molten Pool." Transaction of JWRI. (1972). No. 1 99s – 113s