What can be learned from the welder?

The article endeavours to entertain the reader in thought during analysis of the welders' role in the welding profession. To be a welder is not necessarily a first choice occupation for the up and coming generation as the role is very misunderstood by the layman in society. The conclusions derived from this article should go a long way to improve the image of being a welder and help to recruit suitable fresh blood to join the fraternity of welding. The analysis explores what it means to be a welder and the relationship between the other disciplines of the welding profession.

Introduction

Of all the disciplines that now constitute the welding profession it is the welder who was here first. In some guise or another welders have been around for a very long time, centuries in fact, because even before the onset of the industrial revolution the process of welding had been in frequent use, e.g. forge welding. The prospects of many civilisations throughout history have depended upon the process for the provision of weapons for battle. If the sword had not been forge welded in a satisfactory manner the outcome of some of the great battles of centuries ago would have been very different to the result we know today. The consequence would be that some civilisations, even ours as we know of it today, would have suffered a premature demise with an associated change of history such is the dramatic impact of welding upon mankind.

It is reasonable to state that the achievement of welders was indeed considerable prior to, during and since the industrial revolution. The welders must have worked in a painstaking way in an atmosphere of some ignorance compared to the knowledge base of today yet must have developed skills that proved very effective. Evidently, there should be knowledge of significance to be learned from their previous history but also from current welding practice as we know of them today in the 21st century.

The provision of essential services i.e. oil, gas, water, electricity, transportation etc. in modern civilisation all depend somewhere along the line upon welds being carried out satisfactorily. Nowadays, welders occupy a role that is in the front line of manufacturing operations, they become the most prominent aspect of the welding process and can be regarded as the engineer of the welded joint. Derived from what is true regarding the process of welding, i.e. its possible deleterious effects, a conclusion should be that the welder is the person who carries a considerable amount of responsibility for getting the job right. Poor application of welding processes, be they manual or automatic, in any situation by the welder, completely undermines all the technology input prior to any joint that is to be welded. A consequence of this is that the overall well being of the product is usually affected. Unfortunately, the truth regarding the role of the welder is unappreciated by some management to the detriment of many companies. Without question the welder is therefore a very important person and this justifies why we should ask if there is anything profound we can learn from the journeyman of our profession.

– To investigate let us try to answer some pertinent questions and discuss!

Discussion

Where do we begin to investigate what welders actually do? – As a vehicle for argument let us imagine one of the fusion welding processes, say Metal Inert Gas (MIG) and think about what we would observe from a welder in action. Our immediate reaction would be to make a statement of what actually is happening, straightforwardly, this would be that the welder is welding the joint, see figure.

Consider now the scenario where someone decided to switch off the welding power pack whilst the welder was working on the job. Apart from upsetting the welder, there is obviously a dramatic effect as the arc is extinguished and welding of the joint ceases. Albeit, this is a thought experiment, yet would be true to verify in practice, an important conclusion can be derived. Strictly speaking the conclusion one could derive from this is that a welder does not have a 'direct' influence on the fusion action during the welding process, it is the welding machine that physically influences welding action. Whenever I have been involved in welder training exercises, many of the personnel and to include myself found the conceptual meaning awkward to put into context at first, however this must be done. To investigate the relevance of the observation let us schematically outline what the fusion welding processes like MIG and many others do. In outline:

- ☐ The fusion process melts the parent material,
- ☐ A filler/consumable is usually melted and added to the molten pool,
- ☐ The liquid weld pool is allowed to solidify and cool down to form what we term the "weld".

In order to carry out the above sequence, say for example metals and their alloys, very high temperatures need to be generated for fusion to occur. The heat required to raise the temperature is usually derived from an electric arc, clearly this would be rather difficult for a human being to achieve when the welding power pack is switched "off"! If it is indeed true that the activity of a human being does not 'directly' carry out the weld, as a corollary from this, we should be able to fully automate the welding process, it turns out to be fact that this we are capable of doing. The early forge welders from centuries ago could automate the process by positioning the hitting implement on a suitable platform above the hot metal pieces and use gravity to generate the energy upon impact to forge weld. Serious automation of welding processes would not be possible if there were actions to be applied 'directly' from the welder. Welding processes still need however the human input to function effectively especially that derived from skilled welding personnel, the welder input is evidently 'indirect' in nature. The automatic welding machine therefore still intrinsically needs to be operated by a welder with skill, however, this is contrary to the view held by some management. It would appear in modern industry that management will gladly employ the suitable skilled person to work as an electrician, machinist etc. but are reluctant to do so when it comes to welding operations. Welding be it manual or automatic is far more complex than other trades in industry due to the number of important variables that affect the successful result which makes this behaviour by management very baffling. When it is said that a person welds it is in fact a corruption of meaning despite being the accepted and frequently used terminol-

ogy used by us all. The indirect nature of the work a skilled welder appears to do needs to be defined with a little more accuracy and put into context. So, referencing back to our MIG welder example, in a sense the welder has deceived us, in a very subtle way, by disguising what actually is being done.

How do we discover what the welder is really up to?

To determine what the welder is really up to can be found from exploring a certain way of reasoning. Consideration needs to be given to our perception of quality in welds and its relationship with the idea of achieving perfection.

A welder soon realises that many things need to be considered, say if using the MIG process, before a successful result can be achieved. For example, inaccuracy of ten degrees in a bevel angle may be sufficient to prevent root fusion and penetration for a single sided plate butt weld. The scientific way of expressing this point is that the number of welding variables which need to be set correctly for a successful result are many not few, the desired result being described by some kind of specification. Welders cannot help realise from the onset of their welding experience that perfection is most unlikely. Even if perfection were deemed possible it would still be found as impossible as an objective in the welding environment, due to the existence of many important variables that need to be controlled. Despite the fact a pure scientist may be capable of putting a number to aspects of imperfection, skilled welders take this fundamental concept on board as easily as taking breath, therefore to deal with imperfection is naturally accommodated in the skilled welder bloodstream (if not there at present it should be!). Again this supports my argument about who should operate automatic welding machines as experience in handling these variables is still needed.

By inference then, all welds cannot be perfect in every sense but must contain faultiness to some degree. Corroboration of this conclusion can be derived from the manner by which the quality of a weld is expressed in the various types of technical literature be they textbooks, codes of practice, specifications and or standards etc. All of these means of communicating weld quality do so by stating the permissible level of imperfections for a weld to be fit for purpose, so we have sound agreement with the truth about welding here. So we can deduce from these facts that the welder has something to do with the resulting degree of faultiness in a weld (a definite fundamental point).

Here is our welder using the MIG welding process

Is it true that all welders produce imperfect welds?

Welder skill level is usually related and assessed to the manner by which weld quality is expressed, this can be done by direct reference to the types of imperfection themselves or indirectly by some kind of functional test. What we are now saying then is that welder skill is related to affecting the production of welds that exhibit and contain a recognised level of faultiness that by some means is measured. By definition then welders can only take one course of action, which is to do their utmost to suppress the formation of imperfections. Classification of their skill relates to how capable they are at doing this task when the welding process is applied. If welders persist in thinking otherwise then this is a reflection of poor training. Unless welders appreciate the truth about the fundamental nature of their skill they cannot function effectively as they have no mechanism to improve. It is inevitable that welders will produce imperfection in welds so the immediate answer must be yes to this question.

So a welder produces imperfect welds, what information does the welder need to implement the improvement mechanism?

For approval to weld a joint the welder is usually asked to undertake a simulation type test piece. If the weld passes or fails the specification the welder needs to be informed as to the reason for the decision. From my long career the communication of the result to the welders involved is that they are told virtually nothing and see none of the physical evidence, I find it is a little disrespectful to the journeyman of the profession. When welders know the imperfections/defects especially incurred in a test failure they can implement the technique to eradicate the problem and improve the chances of subsequent welds being acceptable. For this reason non-destructive test reports should be more detailed than they normally are and accessible to the welder.

Is it correct to say a welder can weld 'to' a particular specified quality level with the improvement mechanism?

High quality relative to what are termed low quality welds demand a lower level of imperfections, this can be found by comparing the range of fabrication specifications that exist. So, if welders were asked to deliberately introduce an imperfection level into a weld between that stated in two different specifications of high and low quality, would this be possible? Say for example, the requirement was for between 10 and 15 gas pores, less than 1 mm diameter, in every 150 mm length of weld deposit.

Just think about the practicalities, in order to do this the welders would need to create gas pores at will and count them, evidently an action that is not possible. In order to solve this particular problem, the welding aspect of skill that is only available to the welder is to use known actions or derive new ones that suppress the occurrence of gas pores in welds.

Despite the defined and permitted level for imperfection stated in a fabrication specification or standard the reality is that welders cannot deliberately produce a weld with an exact quantity or distribution of a given type of imperfection, therefore cannot deliberately weld 'to' a standard. The reason is because welders can only take preventive type actions that are essentially qualitative in nature, that is, work to suppress the mechanisms from which imperfections are derived. In contrast, the fabrication industry establishes the weld quality of a product in the reverse direction to the situation asked in the question above where the specification is compared to the imperfection level of the weld produced.

How does the improvement mechanism operate?

The analysis of this latter fact from our investigation gives more insight into what the welder actually does. Actions that suppress the formation of gas pores for example are derived by the analysis of 'actions and their effect' upon weld quality. Another way of expressing this point is to say welding skill has been acquired traditionally by trial and error. Centuries ago this was the only available technique open to the sword makers, due to lack of knowledge, in order to develop the required skills and produce satisfactory weld quality. If welders remain fit and healthy, providing the lessons are learned, then the older should be the better.

The results accumulated over time from trial and error have produced recognisable techniques that are expressed in the various commendable textbooks and instruction manuals published for welder training. Knowledge is expressed in a style with terms of how you weld this joint with this process, which is a point fair enough, however, it is suggested that this can be a very misleading approach. One cannot learn something by purely watching an instructor weld a joint unless it is appreciated what is the purpose of the actions.

For example, if an instructor is welding a plate to plate 'T' fillet with the MIG process the purpose of the particular torch angle used cannot be understood or its value estimated until the weld is sectioned and or fractured to reveal the imperfection level. Derived from the resulting weld quality the welding student learns from action and its effect. If the student welder appreciates and embraces the reasons why the published welder techniques are efficient in suppressing faults/imperfection then the welder can understand the actions of the instructor. To convey this information to welders is of absolute fundamental importance otherwise the welder cannot learn anything. In our example, welders then can exercise deliberate control of torch angle when it is their turn to use the MIG process. If the welder chooses to ignore the significance of these actions then their skill will degenerate into nonsense, a malaise often experienced in industry today to my dismay.

Welders cannot weld to specification requirements, however, despite this point, if the welder executes the techniques of fault suppression with a very high level of skill the resulting welds will by definition be acceptable to all specification and standards be they for a garden gate or a nuclear pressure vessel. Many welders are surprised to be told they can attain such levels of skill. To support this conjecture, regarding the potential skill level of a welder, one should not observe any specifying document for weld quality that is firstly unrealistic in setting imperfection level and secondly not to designate an imperfection free condition. For any welded fabrication that requests the impossible from the welder all attempts to impose inappropriate specifications of this latter nature would produce the same result as trying to work with no specification at all, which is the complete shambles.

In the past and today how does the welder acquire new skills and is this a successful activity?

The welders' needs are to acquire skills from effective training and experience. Nowadays, when a student of practical welding is being trained everything an instructor demonstrates and says must be concerned with the suppression and control of the occurrence of imperfection in a weld. If this is not the purpose of the training then it is difficult to visualise exactly what is being communicated. If one is resistant to the true message of instruction then only nonsense will prevail and the welder will be devoid of necessary skills. Numerous welders find themselves with this condition today – a problem derived from poor training which is not their fault.

Compared to centuries ago, the current knowledge base allows us to explain more accurately the actual function of the action taken by welders. Due to lack of scientific knowledge at the time, the sword makers apprentice would not appreciate the masters' action from the overall manufacturing sequence. It would be difficult to decipher, for example, which action brings about the reduction of oxide impurities? Despite this difficulty, the apprentice would work meticulously to incorporate the correct action sequence in every forge weld attempt. The only way to learn for the apprentice would be by turning sword making into more of a ritual art to be learned by regular familiarisation on a day to day basis. The empirical nature of the welder's task originated and developed from here.

Today, a welder acquires knowledge from the programme of actions by which any person who is a student of practical welding is instructed. It consists of a sequence of actions of what to do from the start through to the finish of applying the welding process to the joint. The action sequence could be very detailed, however, a typical structure albeit of condensed form would be of the following (see Table):

The action sequence detail must always be justified by relating to its function in controlling and suppressing the occurrence of imperfections. Throughout my career whenever I have asked welders regarding the purpose of the actions the reply would be "it welds better". This is a much used meaningless remark, very rarely did someone refer to the imperfection problem. It would appear that the fundamentals of manual welding are not communicated in an effective way, I point the finger to include myself. Gradually over the years the welder established the empirical nature of applying a weld process and the preoccupation with imperfection. Many welders today are resistant to the truth and prefer to believe in nonsense – a fact I find disappointing.

A serious weld procedure document designed by a welding engineer would contain these elements as a sequence of operations to generate a suitable metallurgical condition. In principle, this objective is identical to that of the welder, only the imperfections' nature differs, this is a significant point.

From a personal point of view, I refer to this action sequence as the "routine". This can be as elaborate as any individual desires. Welders build up their expertise and skill by the association of "action and effect" on the resulting weld quality derived from within the various sections of their investigation programme. When welding is being carried out to qualified weld procedures for the manufacture of a product, e.g. pressure vessels, the result of action and effect has already been determined during procedure development. Even in this situation qualified welders still need to use their acquired aspects of skill to work effectively with these weld procedures. Despite this requirement by procedures, in practice, is it a regular action for welders to see the weld procedure for information and instructions of how to weld the joint, the reality is shocking.

Welding action sequence

Action	Example of variables investigated
Cleaning prior to welding	Degreasing parent material Spatter removal from the gun
Preparation of the joint	Alignment of the pipes Machining an appropriate bevel angle
Tacking strategy	Size of tacks to use Positioning of the tacks
Weld parameters	Voltage to be selected Wire feed rate to be selected,
Weld build	Designation of run sequence Size of consumable for each run
Inspection of weld	Surface and or volumetric, which specification to be applied

Many products are made without weld procedures, so here in this situation the demands upon the welder are even greater. It is important therefore that sample/simulation test welds are done prior to shop floor production welding to derive the required skill. Again, is this done frequently by companies? I am afraid not.

Within any training programme classroom work must come before the practical to communicate the fundamentals otherwise the actions of the instructor conveys no information of substance to the student. Every change in joint and its configuration presented for welding is a new problem for the skilled welder to solve. Training of welders is about education in how to derive the optimum welding parameters required for the production of an acceptable weld. With regard to welder training and approval exercises the positive statement to make is that we could do much better.

A functional description of a welder is needed, what is a useful definition?

Definitions are published in the literature in a manner that tries to convey a welder is someone who performs a weld. Based upon the argument of this article I suggest that this is in reality something that is clearly false and misleading. Appropriate recognition of the true skills of a welder is not given by some welder approval specifications. These specifications may state that job knowledge is optional and that imperfections are only an aside consideration and not fundamental to the skill of being a welder. The professional respect given to the welder through these definitions and specifications is considered extremely poor, my personal response is that any skilled welder should feel insulted by them.

An alternative definition of a welder should be along the following lines:
"A skilled welder is a person who has the ability to implement those techniques which are known to suppress and control imperfection levels that can occur in a weld when a welding process is applied."
Within this proposed definition is described the subtlety of the real function of a skilled welder. Some people infer practical welding is a 'black art', in the engineering sense, which is meant as a description of something that works but is intangible, indirect and non-quantifiable. The fairness and accuracy of such a statement seems to be confirmed and corroborated by the alternative definition for a skilled welder, the evidence to support the definition is very strong.

Recognising what welders do, what are the implications for industry?

The implications of this suggested definition is that all welders in the manufacturing environment should be regularly trained and formally qualified to some specification or standard, no matter what the job is. Whenever I have been asked to act as expert witness involving a serious weld failure, a frequent scenario is to observe unskilled workers who are welding products in that industry with no prior training and no welding job knowledge. This sort of activity is truly reckless and one usually finds welds that are 'non-fused rubbish' by comparison with any standard set for welding. The repercussion on the company is usually very costly and completely invalidates the decision to use unskilled labour. Again this supports my argument that when welding operations are automated, the automatic machines should be run by skilled welding personnel.

The use of unskilled welding labour is promoted by the money men of industry in the blind pursuit of profits. From the appropriate introduction of automation money can still be realised by using skilled welders derived from productivity increase, weld quality is more likely right first time and savings from the reduction in corrective actions.

In the associated profession of non-destructive testing all operators of any inspection technique need to be formally trained and qualified to obtain a licence to work with that particular technique, the same principle should be applied to welding in the manufacturing environment. Anyone welding who has received no proper training will not possess the required understanding for what they are doing and should be regarded as being very dangerous, sadly there are many examples of human lives lost due to this activity. If brain surgery requires a brain surgeon then welding requires a skilled welding person!

Is there a relationship between other disciplines in welding and the welder, knowing what the welder actually does? Taking on board that perfection is an elusive objective the mode by which the welder functions must apply to other disciplines in welding otherwise objectives become misguided and unclear.

First for example take the "professional welding engineer" who designs procedures. The objective is to derive the appropriate metallurgical condition that delivers the required mechanical and physicals properties. A potential metallurgical condition that is say hard and extremely brittle can be regarded as undesirable so the procedure must function to suppress this imperfection. An example of this is the problem of fusion welding carbon steels to stainless steels in various thickness combinations, a joint very common in the nuclear industry. The solution can be derived from identifying the imperfection microstructure and installing an action in the sequence of operations. In this case, a suitable preheat strategy has been very effective in solving the problem. In principle, although the actions of the welding engineer are different to the welder, this is the same way welders solve their problems, only the type of imperfection is different.

Second for example take the electrical engineer of the power pack. Welders wish to deliver the appropriate amount of energy input at particular times during a root run on pipe to pipe butt joints. The electrical engineer must design the power pack to deliver volts and amps with adequate precision to allow the welder to fuse under control and thereby suppress lack of fusion imperfections. The demands by the welder should motivate the design of manual or automatic equipment. Manufacturers of power packs who pay attention to the objectives regarding imperfection in welds usually produce very good equipment which sells well. In fact skilled welders can provide useful advice for management who are purchasing welding equipment for a production line.

From these two examples alone, there is a strong indication that all welding disciplines should have the same function and objective, it is only the actions that are different to those of the welder.

Conclusions

What are the lessons to be learned from the skilled welder?

1. With regard to the subject of welding the welder was the first around the scene and discovered the empirical mechanism by which any individual welding process is derived and developed.
2. The welder learns to solve the problems set for the welding process from the results of action and its effect on weld quality, this defines the empirical nature of skilled welders' work.
3. Scientific principles have their place in the development of a welding process but welders have shown the empirical approach must be used to apply the process to make the joint. The empirical science approach is in fact the common tool to be used for all aspects and disciplines of welding.
4. A welder's input to a welding process whether it be manual or automated is indirect, rather subtle yet extremely essential to influence the production of an acceptable weld.
5. The actions of a skilled welder indicate what welding is essentially about which is to influence the level of imperfections in a weld. What any welder must learn is how to work out the welding conditions required for the suppression and control of imperfections, this should be obtained from training, instruction, sample testing and experience.
6. The truth behind what the welder actually does provides the welding profession with a common language for communication with all disciplines of welding, it is the description of imperfection.
7. To become a skilled welder teaches us that we can all possess welding expertise to some level but it should be continually nurtured, to try and be regarded as fully expert really does not have much meaning. Current definitions of a welder are misleading and need revision to reflect the true function.
8. The indicators are that all disciplines in the profession do work in the same manner as the skilled welder so we can say that we are all in the same boat in the fraternity of welding. The philosophy of the pursuit of reducing imperfection when producing welds is something profound that unites us all and is a common goal in the welding profession, first established by the 'welder'.

Final comment: I am not saying that a welder should be likened to a James Bond movie star in society – Just Licensed to Fill.

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