The nature of welding and its relationship with the steel industry

In this unprecedented time of the Corona virus pandemic, Dr France draws parallels to a 'virus' lodged within the engineering industry, which results in forensic engineers neglecting the advice of welding specialists when examining the causes of structural failures, and uses classic examples of catastrophic failures to illustrate his points. He stresses the fundamental symbiotic relationship between welding and the steel industry. By **E J France***

OVER the centuries welding has been an empirical science that has initiated progress in the iron and steel industry. Major progress in iron and steel metallurgy and its processing industries occur particularly when there are simultaneous significant developments in welding progress. This indicates that the fundamental nature of the relationship between welding and the steel industry is a symbiotic one in which both disciplines benefit.

Steel quality has been incorrectly targeted as the cause of major weld structure failures. Experienced welding engineers, have had to analyse the evidence to determine the real cause of these failures, in order to correct the conjectures of the official investigators.

Observation and analysis of the welding fabrication industry of today reveals there exists what we might call, in current times, a virus that is corrupting and eroding the symbiotic relationship. Welding engineering is fast becoming the 'Forgotten Technology' – a most disturbing development.

Q: What is 'welding'?
A: 'Welding' is the action of bonding by the atoms that constitute the mating parts of a joint. There is a common objective for all disciplines of the welding engineering profession and any welding fabrication company (**Fig.1**).

Q: What initiated discovery of the 'welding process', thousands of years ago?
A: It was the desire of mankind to join objects together to obtain and facilitate greater function of tools and ornaments for a civilisation. Joining would have been achieved when the atoms bonded but, at the time, mankind would be unaware that this was the requirement.

The forge welding process first provided an early joining action for the atoms in metallic materials, this welding impulse was crucial especially for the development of iron alloys. Years ago, other solutions for atom bonding, such as smelting and casting that were suitable for such metals as gold and copper, were not readily applicable to iron. The forge welding process stimulated the advent of the iron and steel industry, ie, the beginning of a relationship between metallurgist and welding engineer.

Q: From where did we derive the energy required for the atoms to bond and form a welded joint?
A: Human beings could not provide this energy directly, it had to come from another source, the energy was sourced from the heat of a welding process.

We can now state a fundamental truth about welding: it is that the person we call a 'welder' does not directly weld anything, it is the welding process that facilitates this function.

There is nothing new about the phenomenon of welding, as atom bonding has been present since the early days of the universe, but there have been developments in the welding processes. The bonding energy required for the atoms to combine can be sourced and delivered, for example, from an electric arc, an electron beam or a laser beam, or even friction, all depending on the particular welding process concerned.

To satisfy mans' desire to increase the size of a piece of iron and obtain greater functionality, we needed to facilitate the atoms to bond from one smaller individual piece to another. By using this method we could, for example, move from small arrow heads weighing a few hundred grams to a lintel weighing many kilograms, (**Fig.2**). To do this, forge welding was improved by

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carrying out action and effect techniques, which today we know of as Empirical Science, with the qualifying addendum that welding is empirical science only. It is not possible to predict the resulting weld quality, when applying a weld process, because to do so one would have to break the laws of physics. The fundamental nature of welding was then discovered and established.

We can now state that the driving force inherent within welding processes has facilitated and expanded the use of iron and steel product forms to make fabrications. It is highlighted here, the coming into existence of a mutual dependency in the relationship between welding action and ferrous metallurgy; it was, and is, difficult for one science to progress without the other.

The nature of welding is best illustrated by the manufacture of a sword. Take the Samurai sword maker, these Japanese craftsmen work to an established ritual of actions developed by empirical science over the centuries, which are still in use today. The student of the sword maker, the apprentice welder, would learn the ritual, parrot fashion, in a painstaking way,

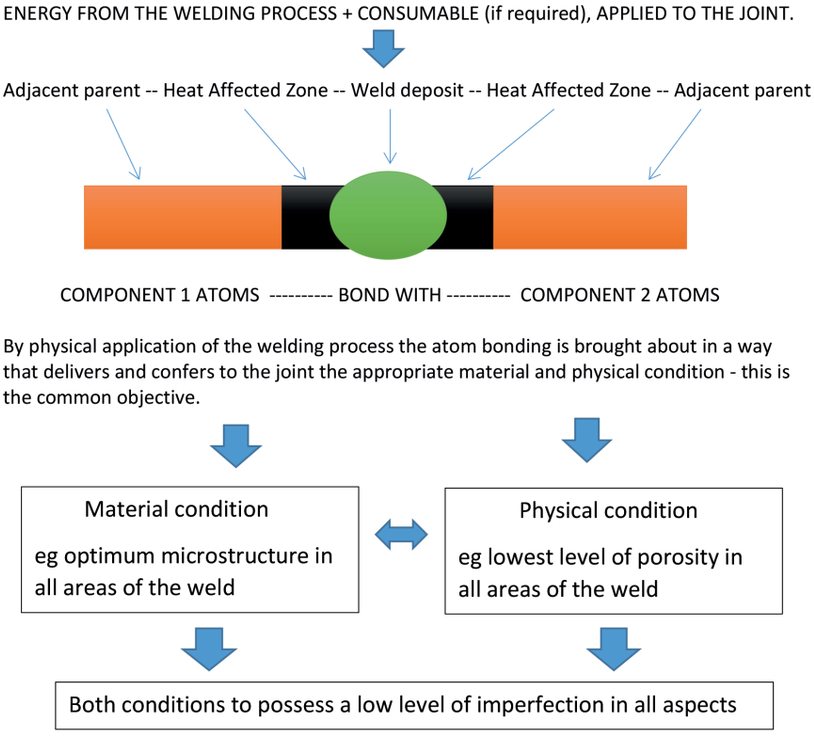

Fig 1. Areas of a fusion welded joint and the common objective of a welding action

Fig 2. A Roman hypocaust lintel over 1m long and weighing some 40kg fabricated by forge welding a number of smaller 'blooms' of iron by repeated heating and hammering

until becoming competent. Today, we recognise the ritual as a weld procedure. The discipline of this procedure is given respect and thereby reinforced in practice by the Japanese sword maker by the use of religious quotations during fabrication, he is rewarded by the derived high quality of the forged welded carbon steel produced.

The success of sword making had a significant influence on the survival of civilisations years ago and as a consequence the welding phenomenon changed history to what we know today.

Centuries ago welding was established as an empirical science to be carried in accordance with derived and tested rituals, today's weld procedures.

Q: Does today's welding fabrication industry respect this truth about welding?

A: No. The current welding industry is in denial of the truth; if it said yes to this question, one actually finds deliberate deviations from this established philosophy. People should be worried about this because it is the reason why we have had catastrophic failure of structures arising from defective welded joints.

Q: For how long did forge welding technology remain the dominant technique for joining iron alloy products together?

A: From thousands of years ago up until the early decades of the twentieth century forge welding was the sole process available for weld fabrication, with blacksmithing and hot riveting techniques predominant.

Q: Where does welding, atom bonding, take place in the hot riveted joint?

A: Within the rivet itself. People outside of the metallurgical and welding engineering profession do not appreciate this significant fact.

Steel metallurgy took off in a significant way in the Victorian era along with mass production of steel for the first time with the invention of the Bessemer process. By using the Bessemer converter, a hot-riveted forge-welded vessel, the development of new carbon steels was eased.

Fig 3. A WW II Liberty ship brittle fracture failure

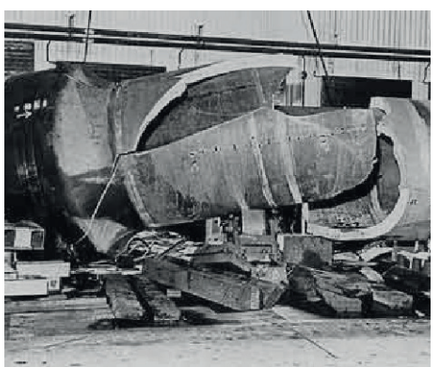

Fig 4. The John Thompson pressure vessel that failed upon hydraulic testing - 'Abandon the weld procedure at your peril'

Fig 5. The fractured brace D6 on the Alexander L Kielland oil platform showing fatigue crack propagation from the hydrophone insert joint – 'No weld procedure – no function' (Pic by permission of The Welding Institute)

Catastrophic failures

Welding and steelmaking matters changed with the advent of the second world war and its demands for military and support equipment. An example of this requirement was the desire to build supply ships, the Liberty ships, more rapidly than before. 'Five ships in five days' was proudly displayed by the California Shipbuilding Corporation in January 1943. A contribution to faster production came from the application of arc welding to replace the traditional hot riveting forge welding technique. When arc welding processes were first used to fabricate the Liberty ships, it exposed a 'material deficiency', in the parent steel – the low toughness of the steel plate at service conditions around and below 0°C. All carbon steels undergo a ductile-brittle transition as temperature is lowered and the aim is to ensure this temperature is well below service conditions. Many early Liberty ships suffered catastrophic failures, breaking in two, even while in port (**Fig.3**).

This deficiency in the steel properties did not mean there was anything wrong from the metallurgical point of view – 'the steel had the properties it had'. The welding process just exaggerated the effect of the steel deficiency on the properties of the weldment. Arc welding plates together creates a continuous path of steel for a crack, initiated at a stress raiser such as an arc strike or machined notch, to propagate through, unlike riveted plates where a crack initiated would stop at the joint to the next plate as there is no continuous path of metal. It is important to appreciate that riveted components are still used, for example, in welded pipelines as crack arrester joints, installed every few kilometres

in order to prevent complete failure of a pipeline due to such crack propagation which can reach the speed of sound.

The ships required a different type of carbon steel for welded construction which was brought about by alloying. The composition of the parent steel plate was modified, with additions of manganese and silicon, to lower the transition temperature and so improve its fracture toughness, and new weld procedures were derived and tested for the production environment. Afterwards, fewer catastrophic fractures with these ships were experienced for the reason we now know: that the material and physical condition in all areas of the weld was reduced in imperfection level as stated in **Fig 1**. This result showed and confirmed a 'symbiotic relationship' between welding and the steel industry, that had been characterised over the previous centuries, now employed to good effect.

Where metallurgists seek to develop new steels they need to consider if the steel is receptive to the application of welding processes. If say, a newly developed and improved corrosion-resistant austenitic stainless steel cannot be welded with electric arc processes and the associated consumables then its application to industry would be somewhat limited.

After the second world war, this symbiotic relationship flourished, until an incident in 1965 focused attention and revealed a disturbing development in welding engineering. This was the well-documented brittle failure of the John Thompson pressure vessel, upon hydraulic testing (**Fig. 4**). In this example, weld procedures were derived and qualified for fabrication of the joints, otherwise the insurance company inspector would not have allowed welding fabrication to proceed. The failure analysis investigators found evidence that the weld procedures were not carried out to the full, but abandoned part way through the sequence of operations. This abandonment of weld procedure was in complete contradiction to the reasons for doing the qualification exercise in the first place. The decision to do this action proved costly in economic terms and threatened worker health and safety.

This decision has to be documented as the behaviour of people who were irresponsible, and ignorant of the need to fully follow the welding procedure, a disturbing development in welding engineering.

Q: Was an experienced welding engineer asked for input when the decision was considered?

A: It appears unlikely. It must be assumed that the JT welding engineer had no say in the matter. Was this a first sign of the virus infection in a welding fabrication company? A derived, qualified and tested weld procedure for a joint, using the fundamentals of empirical science, establishes the parameters for the weld processes to be used and the physical manipulation techniques for the welder to apply.

Q: Was the true cause of the John Thompson vessel failure revealed by the investigation team?

A: No. Investigators did not recognise, nor understand, the significance of the decision made by the manufacturer to abandon the weld procedure, instead they became incapable of thinking straight. Natural features of the steel plate and forgings were blamed for the cause of failure, comments which are proven to be ill-founded, incorrect and ridiculous. The investigation report, (Ref.1) tarnished the steel industry in an unjustified way. Inevitably, the investigation then drifted into a fantasy world of misleading gobbledygook by suggesting a fracture mechanics approach to assess parent steel for fracture avoidance, as a solution to the problem. This is and was a load of nonsense.

While the investigators identified the physical reason for failure, from a hydrogen embrittlement mechanism, they did not understand the reason this arose. This was the consequence of a fabricator failing to implement, fully and correctly, the documented instructions of a designated weld procedure to a joint in the production environment. The result was that the 'common objective' as illustrated in **Fig.1**, could not be achieved. This simple act and mistake was the fundamental and true cause of the vessel failure upon hydraulic testing. By not delivering the common objective to the production joint, the weld, by definition, possessed excessive imperfection in all its aspects. Derived from the presence of these imperfections, now classed as defects, the weld now facilitates a variety of deleterious and dangerous failure and fracture mechanisms to come alive and operate.

Q: After the John Thompson incident was there a renaissance in the symbiotic relationship between welding and steel metallurgy?

A: Yes. Round about this time and well into the 1970s there was the occurrence and advent in Europe of the North Sea Oil industry. During this time there were outstanding developments in steel metallurgy and product forms for the construction of the rigs, welded pipelines and other equipment required for the harsh operating environment. In addition, there was a parallel and significant development of welding consumables that were compatible with the new steels. Emphasis was placed upon developing weld procedures, approval of welders and simulation joint tests. Millions of dollars were spent doing this exercise. So there

was a kind of renaissance in the symbiotic relationship between welding and steel metallurgy, common sense seemed to have been restored, being reinforced by this industrial activity in the North Sea.

In the heady environment of this time, when in welding engineering terms we could have perhaps made the claim, 'we seem to be doing it right', why in 1980 did we incur the collapse of the Alexander L Kielland oil platform, with the loss of 123 lives? The reason was that in 1965 the true understanding of welding had been infected by a virus that corrupted truth, this virus was still present when this platform was constructed in 1976, at the supposed peak of good behaviour by welding fabricators. Confirmation of the virus sickness can be derived from examination of **Fig.5** which is from the authors' forensic analysis of the failure, (Ref 2). All the joints on a horizontal brace were to be welded in accordance with the mandatory instructions of the fabrication specification for the oil platform. These joints were specified as full penetration butt welds with visual inspection after completion of the joint. The official investigation yet again claimed that the brace and insert steel plate was to blame for the failure. It was proven at the time that the steel complied to specification and there was no evidence of defects emanating from within the steel itself, therefore the steel was satisfactory for purpose (Ref 2). To briefly explain the true cause of the failure:-

On this brace, designated D6, one joint was fabricated correctly, which was the drain hole, but the other identically specified joint, the hydrophone insert, was not welded correctly to the requirements of the fabrication specification.

The fracture originated as a fatigue crack from a defective weld bead in the hydrophone insert joint. This joint was incorrectly designated as at a low stress zone and so was left to the welder both to decide on method of welding and to inspect the work after completion.

The failure of this brace and the 'domino' effect resulting from it, which caused the capsize of the structure, should be of no surprise to welding people today, but it was a surprise to everyone involved at that time. Does the reader of this article get a sense of déjà vu here?

The hydrophone insert was already cracked when it first went down the slipway into the sea, evidenced by traces of paint on the fracture surfaces.

Q: Is the virus still present today in the 21st century, 40 years after the Alexander L Kielland incident? Further, is the virus more virulent and has it created an even worse condition in the weld fabrication industry?
A: Yes, to an extent the situation has become 'rotten to the core' as we say! Currently, and as time goes by, the breakdown in the symbiotic relationship continues with deleterious effect on weld quality of fabrications. This fact should worry everyone. Dangerous complacency has set in at fabrication companies where essentially welding operations carried out do not reflect the information contained on the derived welding procedures. Despite the responsible actions by international welding authorities to issue new welding fabrication specifications to cover a broader range of welded products, fabricators pay only scant recognition of this and exhibit contemptuous behaviour towards doing what they should be doing. It is also disappointing to report that the new specifications still allow welders to make up their own welding parameters and thereby these specifications are totally contradictory and improve nothing. An example of this is BS EN ISO 3834 and its part 4. Clearly the correct welding message has not got through to the committees defining these specifications.

Q: Is welding engineering fast becoming the Forgotten Technology?
A: Yes

Q: Why is it that some members of the welding fraternity, in all the disciplines therein, cannot recognise from past evidence that welding engineering is suffering from a technical viral disease?
A: They have the virus, but don't know it.

Q: Why is it that still today many welding fabrication companies permit their welders to weld fabricate without reference to a weld procedure?
A: They also have the virus.

Q: Does the modern welding fabrication industry give respect and acceptance to the truth about welding and its relationship to the steel industry?
A: No. References 1 and 2 confirm this as they do not demonstrate they give the respect to weld quality. So what do they care about? Profit. We must conclude so from the evidence. ■

References

1 British Welding Research Bulletin vol 7 (6) p149 – 178, 1966 Anon
2 The Alexander L Kielland Disaster Revisited – Journal of Failure Analysis and Prevention, Vol 19, Issue 4, August 2019, p875 – 881 by E J France