HARDFACE TECHNOLOGIES by POSTLE INDUSTRIES

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UNDERSTANDING STRESS RELIEF (CHECK) CRACKING IN HARDFACING WELD DEPOSITS

by Bob Miller, Materials Engineer

How to control check cracking and use to your advantage.

Download Data Sheets
Glossary

The mere mention of the word "crack" sometimes carries a fateful connotation. **Fig. 1** This is certainly true of weldments

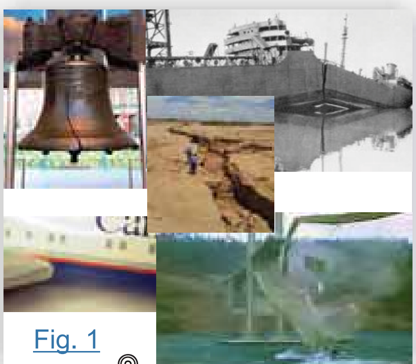


Fig. 1

in general. However, cracks in hardfacing deposits are quite common, particularly with the alloys known generically as chromium carbides. Strange as it may seem, there are many occasions where cracks are welcomed and even encouraged in these alloys.

Given the multitude of hardfacing alloys available, why do some crack and while others don't? Why do some of these weld deposits lead to spalling? Can the cracking be controlled? Can the cracking be eliminated? Are there applications where cracking is not recommended? These are all excellent questions and hopefully this article will clear up some of the mystery regarding check cracking.

Terminology

First, let's look at the terminology. Some hardfacing weld deposits crack upon cooling, often referred to as "*stress relief cracking*" "*check cracking*" or *"cross checking"*. Essentially all these terms refer to the same surface cracks observed on some hardfacing alloys. Stresses induced by molten weld bead shrinkage become so high that they literally produce a transverse crack that is perpendicular to the weld bead direction. **Fig. 2** Once the crack develops the stresses are reduced or relieved, thus the term *stress relief cracking*. The term *check* can be thought of as a crack whose progress is put in *check* or stopped at the interface of the base metal heat affected zone(HAZ) and the weld deposit. This is very much the same as a border check point, or a gate where traffic is stopped before entering into another zone. Cross checking refers to a crack that occurs "*across*" the weld bead. Check cracking will be used throughout this article, but the term stress relief cracking and cross checking can be substituted for convenience.

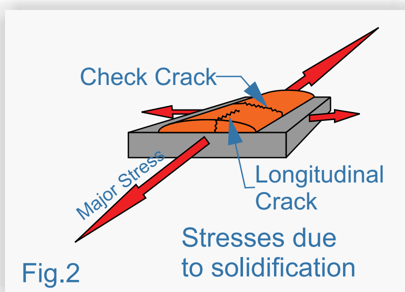


Fig.2

Which alloys check crack and why?

Check cracking generally occurs in iron based chromium carbide type alloys, and nickel and cobalt base alloys to a much lesser extent. The iron base chromium carbide alloys are quite attractive because they are affordable and protect base metals against abrasive wear quite well. But they do crack.

Molten weld deposit grains form outwardly much like the layers of skin on

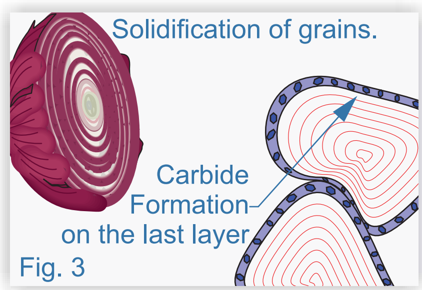


Fig. 3

onions. **Fig. 3** As each layer is formed, it becomes richer in alloy content than its predecessor. The very last layers are enriched and this is where the chromium and carbon combine to form chromium carbides. These last layers to solidify are referred to as "*grain boundaries.*" The grain boundaries are inherently the weakest structure in hardfacing deposits, but become extremely sensitive to cracking when chromium carbides form on them during the solidification process. Check cracking results when the cooling weld deposits generates enough critical stress.

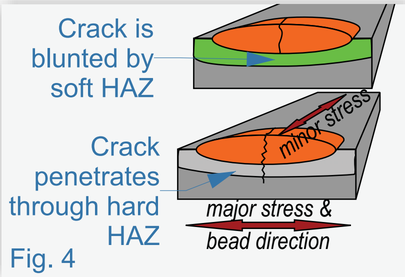


Fig. 4

Fig. 4 shows the shrinkage stresses on the solidified weld deposit. Note that the highest stress induced is parallel to the bead direction, which is why a crack that is perpendicular to the bead direction develops. The crack immediately races toward the base metal HAZ. The condition of the HAZ then dictates if the crack will enter the base material causing spalling and catastrophic failure or be blunted and stopped. Soft HAZ hardness values, usually under 35Rc to 40Rc, will blunt the crack, while hardness values above this will be sufficiently brittle and allow the crack to penetrate into the base metal and lead to a catastrophic failure. The check cracks usually occur at a regular frequency that can be anywhere between 3/8" to 2" (9.5 to 50.8mm) apart. The check cracking frequency is highly susceptible to a number of variables which include chemistry, preheat temperature, cooling rates, bead shape and component profile and dimensions. Let's take a look at these variables individually.

Chemistry: Increasing carbon or chromium or both generally produces more check cracks.

Preheat Temperatures: The higher the preheat temperature, the lower the frequency of check cracks. Higher temperatures encourage slow cooling rates, giving the weld deposit time to distribute the shrinkage stresses.

Bead Shape: Flat or concave beads tend to produce more check cracks, but this may be also dependent upon whether the weld bead is a stringer or weave type deposit. Stringer beads generally increase crack frequency.

Component Profile. Cylindrical objects as opposed to flat objects will generally produce more check cracking. Thicker base materials tend to produce more check cracks.

So, it appears that the chromium carbide family typically check cracks. Does that also mean that if another iron base carbide family is chosen, such as titanium carbide or niobium carbide, that check cracking issues are going to be encountered? Not necessarily.

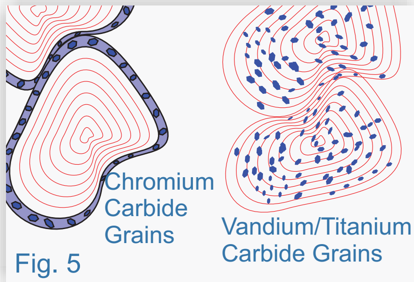


Fig. 5

Fig. 5 These latter alloys contain elements that form carbides in the very early stages of solidification and don't usually form on grain boundaries. They sometimes act as grain nucleation sites. Therefore, check cracking is not encountered. Alloys containing boron also crack, but in a more random manner and for entirely different reasons, which are beyond the scope of this article.

The value of check cracks.

Check cracks are normal and expected in the chromium carbide family of hardfacing alloys, but still many assume that all cracks are bad news. While this notion makes common sense, the reality is that these products are used extensively throughout many applications without incident. Contrary to popular belief, check cracking can be quite useful. Plus, the frequency of forming and their properties of check cracks can be somewhat controlled. Their most valued asset is in distortion control. Distortion is the result of high stresses that are created during the solidification of the weld deposit.

If non-check cracking products were being deposited, distortion would certainly be quite noteworthy and check cracking would be absent. However, if check cracking deposits such as the chromium carbide family were used, numerous cracks would relieve the high stresses and distortion would be minimal.

The low distortion concept is quite prominently displayed during the welding and bending of overlay plate. **Fig. 6** These plates consist of one to

Fig. 6

three layers of chromium carbide deposited onto 1/4" to 3/4" (6mm to 19mm) A36 or mild steel base plates. Welding is accomplished with 4 or 5 welding heads, spread across a 4' to 8' (1.2m x 2.4m) wide and 10' to 20' (3m to 6m) long base plate that

Fig. 7

ranges in thickness from 3/8" to 5/8" (9.5mm to 16mm) thick. It takes approximately 4 to 8 hours to complete just one layer. During the time of welding on the clamped base plate, tremendous stresses and distortion occurs. But because each weld bead check cracks approximately every 1" (25.4mm), distortion is minimal. Closer spacing of the check cracking will produce even less distortion.

Fig. 7 shows the distorted as-welded plate being straightened. And again, the check cracks aid in the forming and straightening process by allowing

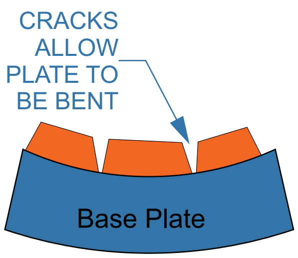
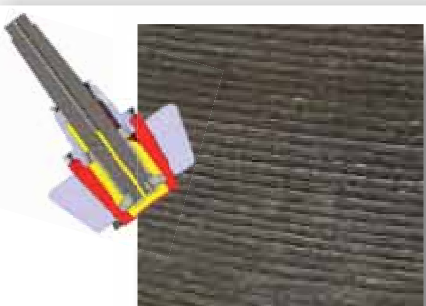


Fig. 8

the bending forces to act upon the mild steel base plate. **Fig. 8** Surprisingly enough, the finished plates can be rolled to a radius of 4" to 5" (101mm to 127mm).

The example presented above clearly demonstrates the value of check cracks. Without check cracking, the fabrication of overlay plates would be almost impossible.

The same principal applied to plates can be applied to other components


Stringer Beads Applied to Pulverizer Roll.
Fig. 9

such as NiHard pulverizer rolls. **Fig. 9** In the past, standard or conventional hardfacing procedures with chromium carbide products produced spalling and catastrophic failures prior to roll installation. These results plagued the industry for years until someone started welding very narrow stringer beads on room temperature rolls, which produced numerous check cracks. In fact, a specification was written that stated that the check cracks are not to exceed 3/8" (9.5mm) apart. Any further separation would lead to spalling and roll rejection or failure. This procedure was further enhanced by trickling water on the back side of the roll to help ensure the correct check crack pattern.

Check cracks can be controlled. The very dynamics of check crack initiation and subsequent movement defies the notion that they can be controlled... but they can. Fatigue cracks, for example, grow very slowly and only after repeated cycles over long periods of hours, days or weeks. Conversely, check cracks are initiated instantaneously and travel at the speed of 4,500 mph to 11,000 mph (2 to 5 kilometers per second). While controlling cracks at this speed would be quite a challenge, controlling their site of initiation and their ultimate travel destination is well within the welding industry's control. In fact it is well within the control of the welder's capabilities at the control panel.

Thus far it has been established that check cracks form because of shrinkage stresses during the weld bead solidification process. Furthermore, the shrinkage stresses are greatly influenced by the shrinkage rate disparity of the two materials involved - the base material shrinkage and the weld metal shrinkage. If this disparity can be altered, then the shrinkage stress can be altered, and in turn the check crack frequency or distance between check cracks can be altered. **Fig. 10** As it turns out, the old standby parameter "preheat" and

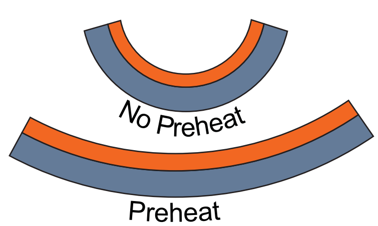


Fig. 10

"post weld cool down" procedures will control the initiation sites of check cracks. As the preheat is increased in the base material, it expands. This expansion reduces the disparity between the weld deposit shrinkage and base material shrinkage, and thus reduces the shrinkage stresses. In turn this decreases the number of check crack initiation sites.

This begs the question regarding overlay plate. The base plate is fairly thin and heat build up is inevitable. With 4 or 5 welding heads operating, each at about 600 amps, why are there so many check cracks? The answer is quite straightforward - the weld beads have a flat contour which is controlled by varying the arc voltage. Higher voltages tend to produce

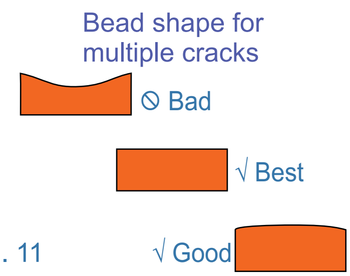


Fig. 11

flatter weld beads. **Fig. 11** Some manufacturers have resorted to applying water on the welded surface of the plate to induce cracking. While it does accomplish a better crack pattern, this is a risky procedure because the entrapped hydrogen from the water can lead to hydrogen cracking and catastrophic failure.

While good check cracking patterns can be developed on room temperature or cooler components, the base metal metallurgy or chemistry may call for preheating to avoid HAZ high hardness problems. For example, a 4340 base material would normally require a minimum of 400°F (204°C) preheating temperature. This can be problematic for very large components, and localized preheating has to be employed. Under normal circumstances, a weave type deposit would cause the check cracks to be developed too far apart, which could lead to spalling. A more prudent approach would be to apply stringer beads. This type of bead shape is more prone to check cracking. This is what solved the pulverizer roll problem.

A rather unique application of chromium carbide alloys demonstrates yet another use of check cracks. Swing-hammer surfaces are routinely hardfaced with chromium carbide products. The hammers are ganged or clamped together **(Fig. 12)** and stringer beads applied to the com-

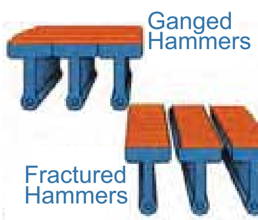


Fig. 12

plete length of the ganged hammers. The welding arc is not extinguished at the end of each hammer. When welding is completed, the entire hammer(s) appear to be welded together. However, at each interface is usually a check crack, and simply dropping these hammers on the floor is enough to break the hammer(s) apart. This is not likely to happen with a non check cracking product.

Caution.

The values of check cracks are great, but they always don't work well. In cases where rebuilding the same component a number of times, it is essential to understand that check cracks will ultimately lead to spalling. Specifically, when rebuilds are applied over the old worn deposit that has not been removed prior a new layer of hardfacing, spalling will eventually occur. This is related to the metallurgy of chromium carbides and the internal movement of carbon into high concentrations in the fusion zone between weld metal and base material. The high concentration leads to a very thin but powerful brittle zone and ultimate failure. Furthermore, debris from field operations may be lodged in the cracks at the time of hardfacing. This debris can cause major defects in the hardfacing deposit, which may lead to spalling.

Probably the most dramatic hardfacing application of chromium carbide check cracks contributing to field problems and unusually high rates of spalling involves the oil field hardband (hardfacing) of drill pipe connections known as "tool joints." The leading chromium carbide hardbanding product suffered from the two failures previous stated...repeated re-applications and check crack debris. As little as five years ago this product was the hardbanding market leader, despite its poor performance. In 2009, Postle Industries introduced Duraband® NC, a non-cracking, highly abrasive resistant wire to the oil field. Today Duraband is the world wide hardbanding market leader. In fact the manufacturer of the chromium carbide hardbanding wire has taken the product off the market. Duraband changed a world wide market and more importantly changed the root thinking in regards to check cracking products.

Chromium carbide check cracking products are popular and wear quite well, but there are numerous applications where check cracking is neither desirable nor tolerated. Some have speculated that probably 50% or more of hardfacing applications fall into this category. Steel mill roll rebuilding, forging die repair, and railroad track repair are just a few of the applications that non-cracking products are used. Product selection can be confusing and our staff is standing by to assist in any way possible.

Summary.

Check cracking or stress relief cracking can positively serve many hardfacing applications using chromium carbide products. High stresses are built up as the weld metal solidifies and cools, which ultimately leads to a multitude of check cracks. The frequency at which they occur can be influenced by preheating, cooling rates, and bead shape. As in any type of hardfacing application, base metal chemistry and metallurgy have to be taken into account. Mild steel, non-magnetic stainless steel, and manganese steel base metals are quite receptive to check cracking, while low alloy steels and cast irons require careful consideration of heat affected zones(HAZ) hardness values. Chromium carbide alloys should not be used where there is considerable impact, as spalling may occur. In these cases a non-cracking product such as Postalloy 2826, Super Edge or Ultrashred 580 should be considered.

Check cracking may have its unique benefits to hardfacing deposits, but they should always be carefully examined with respect to their direction, depth and in particular, their HAZ implications. High hardness HAZ can lead to catastrophic failures, which are costly and have a negative impact on production. If there is any doubt, our staff can help.

Bob Miller
Materials Engineer
Postle Industries, Inc.

Bob has 45 years experience in hardfacing metallurgy, tubular wire formulations and wear applications. He has authored 6 hardfacing US Patents, the most recent in the Hardbanding field. In addition to writing many articles, he is currently engaging in hosting hardfacing Webinars. Please email or contact him to schedule an event for you or your company.

ADDENDUM: FUSION ZONE CRACKING

On page 4, in the first paragraph of the "Caution" section, I briefly touched on a subject that needs to be addressed in more detail, "fusion zone cracking." Hence the addendum. To illustrate this type of cracking, let's look at a very typical application.

Application: We have mild steel hammers (ASTM A36) to which we deposit 2832 SPL, a chromium carbide hardfacing wire from Postle Industries. According to the data sheet, we can elect to deposit two layers maximum, and we do, giving us about a 1/4" (6.35mm) thick deposit. We have proper stringer beads and a good check cracking pattern throughout the deposit surface. We have done everything right.

The hammers go into service, wear over time and are subsequently hardfaced again. The hardfacing and re-hardfacing procedures are done properly for four cycles. But on the 5^{th} cycle, the hammers never make it out of the shop because the completed hardfacing deposits have completely lifted from the base material. Those who witnessed the cracking proclaim that the first layer and base

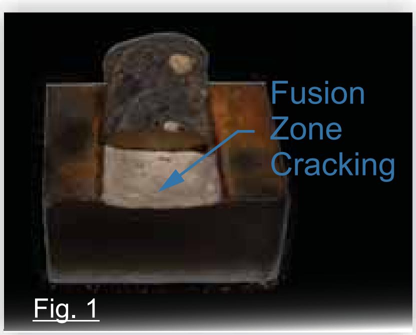


Fig. 1

material were not a metallurgically bonded. **Fig. 1** They convincingly point out that the A36 surface is a perfect mirror image of the bottom of the first layer and shaped the same as the stringer bead. They are right, and it is a perfect fit. Thus it was never tied into the A36 base. But wait a minute, is this observation the legitimate cause for the failure? A further analysis concludes differently.

Fusion Zone Cracking: I would like to introduce a new term, "Fusion Zone Cracking."

So what is a fusion zone and how is it different than a heat affected zone or HAZ?

This is an excellent question and the illustration in **Fig. 1** will help to clarify. Note that the fusion zone (yellow) is quite thin. The fact of the matter is that the fusion zone (or FZ) is much thinner than depicted in Fig. 1. In fact, it may sometimes be indistinguishable from the other zones. It is there, however, and we will see just how critical it can be to the integrity of the hardfacing weld deposit. Also note that each zone

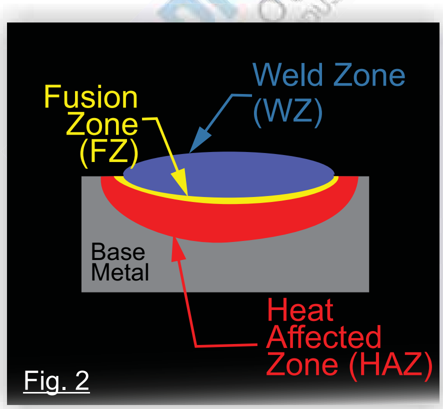


Fig. 2

appears on the surface of the base metal adjacent to the weld zone (or WZ). **Fig. 2** This observation implies that random multiple defects within any of the zones in Fig. 1 will possibly reveal themselves on the

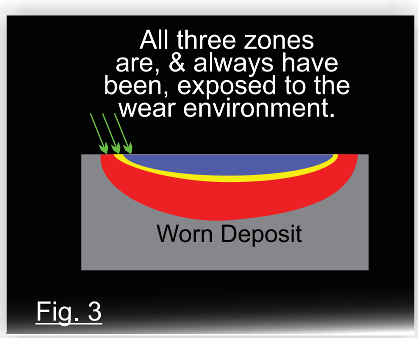


Fig. 3

surface. **Fig. 3** It is erroneous to think that, for example, the fusion zone cracking or HAZ cracking is buried beneath the weld bead and does not pose a threat even in worn deposits. It is important to understand that whatever metallurgical transformations exist in the HAZ, FZ or WZ are always present on the base metal surface. Of course, if the wear is deep or wide enough to wipe out these zones, then they are no longer an influence on the surface of the base metal. This concept will become important in the future discussion.

Now that we know that there is a FZ and that it appears predominately, but not entirely, buried beneath the WZ, it begs the question;

What makes it so different and how does it lead to FZ cracking?

The fusion zone is the boundary between the cooling molten weld metal and the molten section of the base metal. There are many variables that affect its structure, but for the sake of this document it is simply a zone that is a blend of base metal and weld metal whose structure can

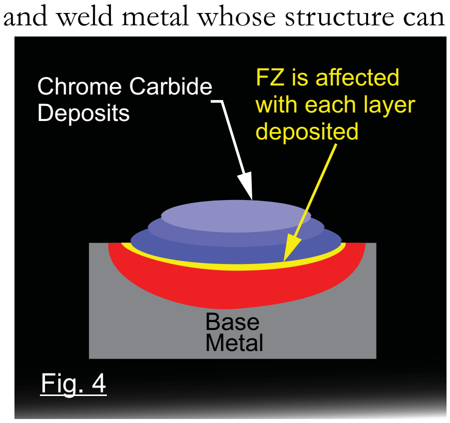
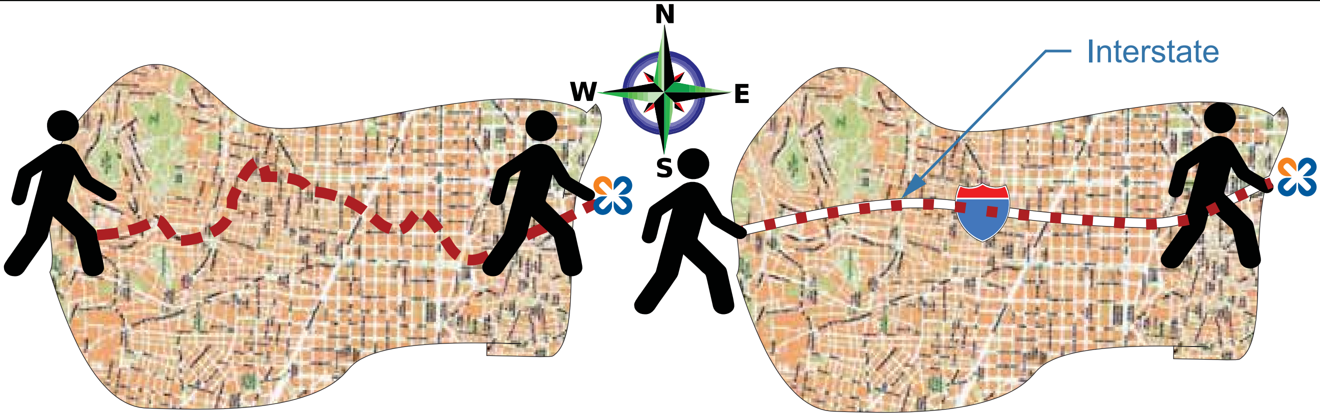


Fig. 4

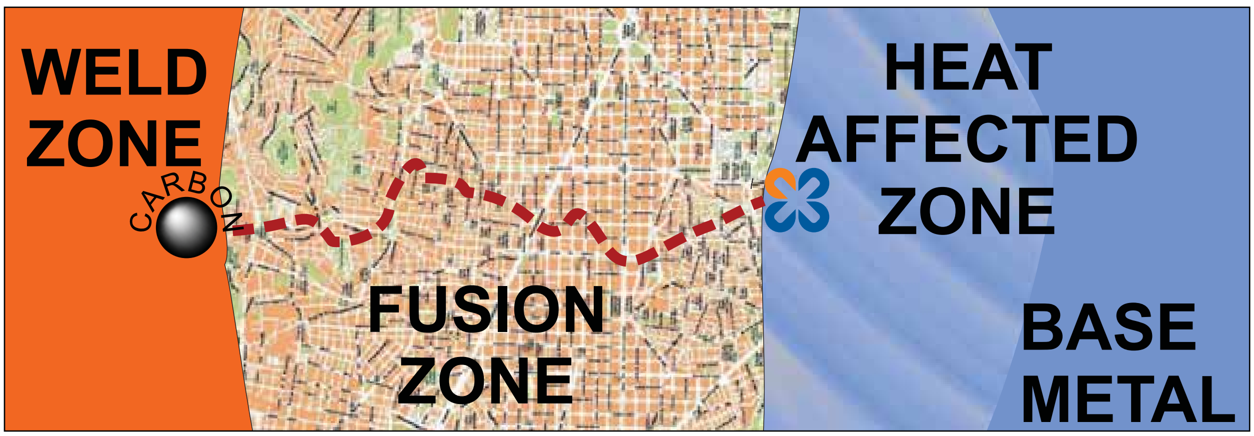
be altered by the heat of the welding arc – as we shall see. **Fig. 4**

To better understand Fusion Zone Cracking, allow me to introduce a new concept: "carbon diffusion." The concept of carbon diffusion states that carbon will migrate from a higher concentration to a lower

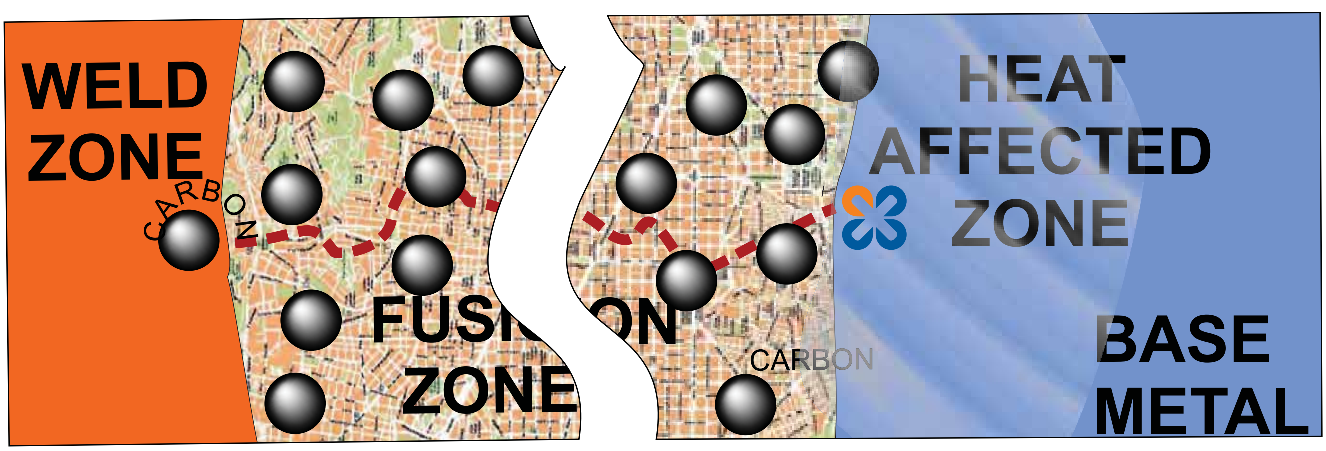


The ability to cross a busy city relies on the structure of the city. Without main thoroughfares, navigation would be non-direct and time consuming. In addition, the long route would no doubt create more opportunities for trouble.

However, if the city structure encompasses main thoroughfares such an interstate, navigation would be direct, much less time consuming, and much less prone to hazzards than the longer route.



The fusion zone of a hardfacing weld deposit is much like a city structure. Some are more porous than others and allow carbon to diffuse quickly, while others are more complex and impede carbon diffusion, which exposes the carbon to form carbides and hardening in the zone.



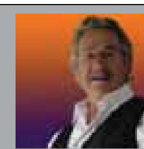
Fusion Zone cracking occurs when the diffused carbon in the fusion zone accumulates, combines, and hardens the FZ structure. Added stress from weld metal cooling contributes to the cracking and lifting.

It is surprising how often we use the word "crack..." within the English language.

CRACKS ME UP
FELL BETWEEN THE CRACKS
BETWEEN A CRACK AND HARD SPOT
CRACK UP
CRACK DOWN
CRACK SHOT
CRACK HEAD
CRACK A SMILE
HE'S CRACKED
CRACKED UP TO BE
CRACK A JOKE
SAFE CRACKER
CRACK OF THE WHIP

Crack PopUp

Bob Miller, Materials Engineer
Postle Industries, Inc.



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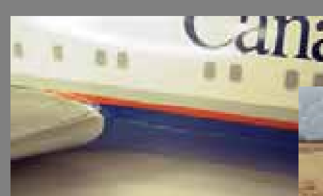
Bob Miller Bio

Liberty Bell USA

World War II Liberty Ship

Tacoma Bridge USA



Canadair Wing Fracture

San Andreas Fault
California USA

Fig. 1

GLOSSARY OF TERMS

Boron	An element that forms borides used for good abrasion resistance.
Distortion	Warping or bending. Used to describe the result of welding.
Grains	All metals are made of grains that form as the molten mass solidifies.
Grain Boundaries	As grains grow they collide with one another to form grain boundaries.
HAZ	Heat Affected Zone is the zone of base metal whose structure has changed due to the heat of welding arc.
Hydrogen Cracking	Cracking that is induced by the formation of Hydrogen either from water or other hydrogen containing compounds.
Nucleation Site	That site where the grains begin to form - often occurs wherever there is a carbide or other foreign matter.
NiHard	A grade of hard cast iron containing nickel.
Preheat	The temperature that the base metal is heated prior to welding.
Pulverizer Roll	Sets of rolls that are used to pulverize and grind coal and other materials.
Spalling	A type of surface fracture that results in the complete removal of an area of that surface. The pieces removed are typically the thickness of the weld deposit and vary in area from the size of a button to a small potato chip.

Glossary PopUp

Links to Chromium Cabide PDF Data Sheets Located on www.postle.com

WIRES	ELECTRODES
2817	210HD
2820	214
2821	215HD
2832	216HD
2834	217HD
2836	218HD
PS133	219HD
Durachrome G	220HD

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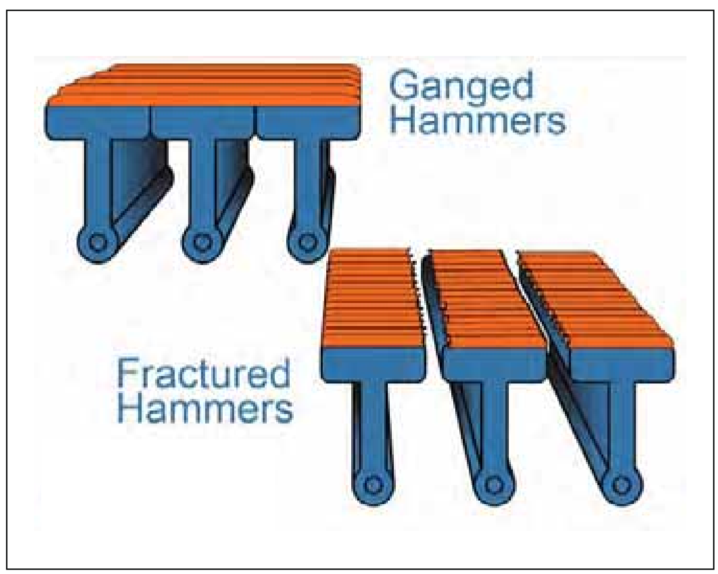
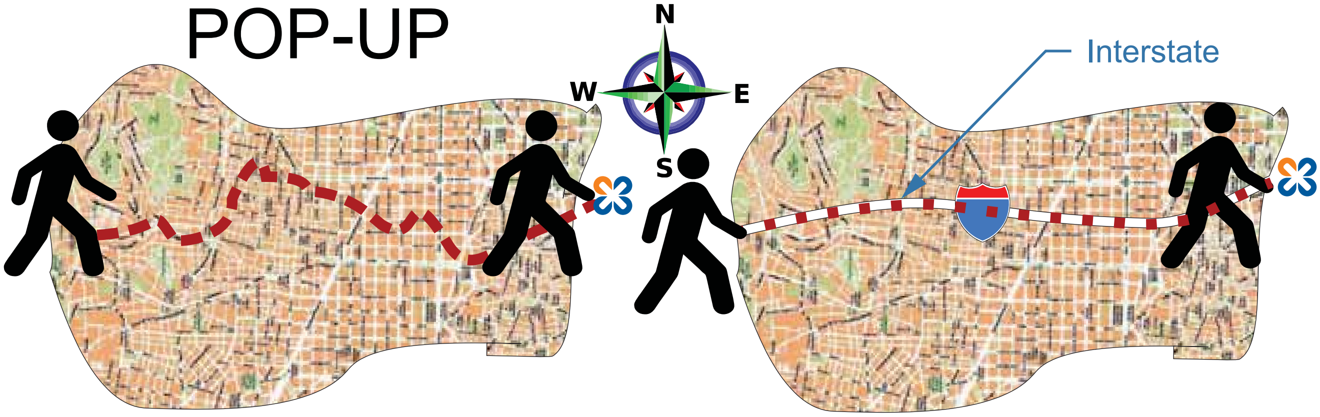


Hammer PopUp

POP-UP



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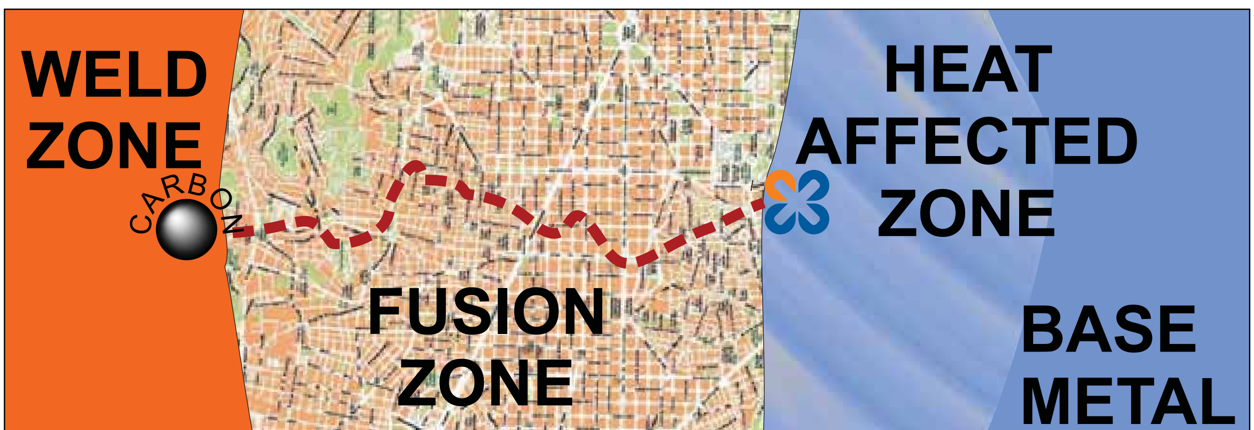

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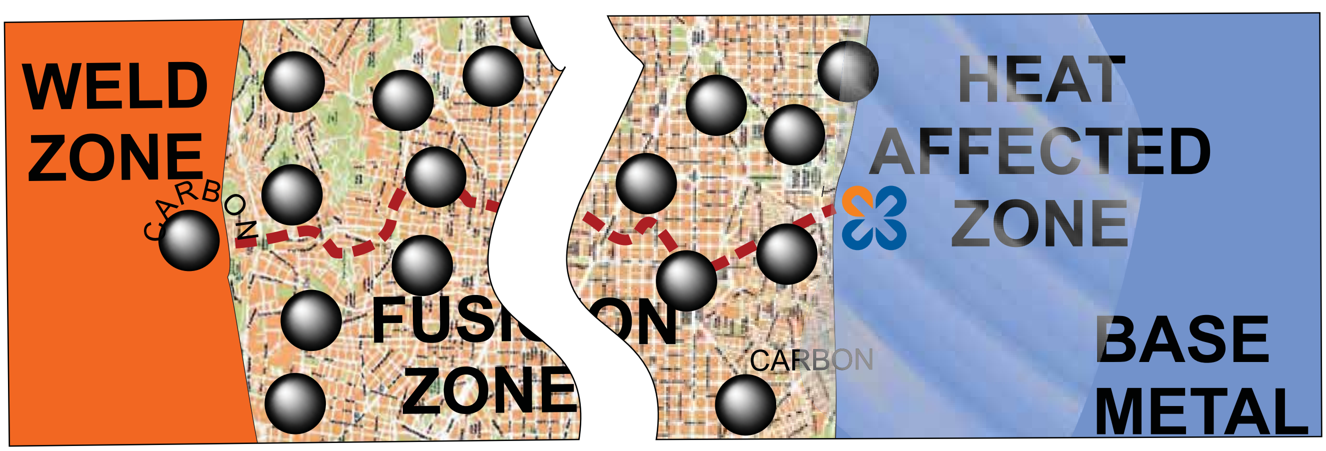

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