THE SCIENCE OF SOLVENT WELDING

A technical presentation for specifiers and owners

about the inner workings of solvent cements

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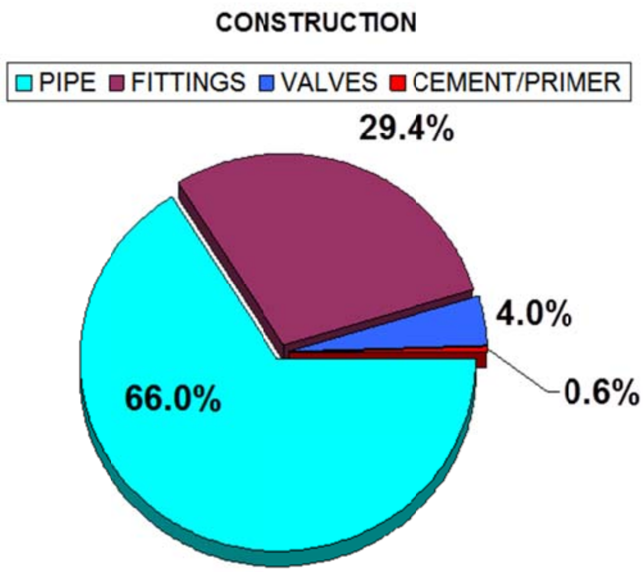
Often time, things that are perceived to be simple or easy are the ones most overlooked and in the piping business this in turns brings problems, failures, high maintenance costs and with all that comes a 'reputation'. Sometimes this applies to solvent welding or, as it is more commonly referred to, 'solvent cementing' (SC) and that is a shame because when properly understood and implemented it is bar none the most cost effective, most reliable, most resilient, strongest and longest lasting way of permanently joining vinyl and ABS piping systems.

Let me start by showing something that amazes me every time I look at it:



What this pie chart shows are the cost allocations for the purchase of pipe, valves, fitting and cement (primer if needed) in construction (commercial or residential). Although there can certainly be variations of the shown cost allocations depending on the building or material used or sizes, the 'magnitude' of the percentage of the cement compared to the PVF will not very by much. In an industrial application it could be as high as 1% because there tends to be a lot more joints (but also pumps, tanks, actuators, etc.). Yet, if that miniscule percentage of the bill of material cost does not work because the wrong products are used, because inferior quality is chosen or because the product is not used correctly the remaining 99+% is in jeopardy.

When anyone argues that all cements are the same and price is the only differentiator, when choices are made to bring the cheapest contractor regardless of experience or expertize, when Engineers refuse to include in the specification that the contractor must either show certification or needs to be trained and/or certified by the SC provider (certification that Weld-On provides for free), I am frankly stunned.

I write this paper to bring clarity to what solvent welding really is--how it works, why it works, what is needed for it to work as advertised, what is the relevance of pipe and fitting dimensions and tolerances, what is the correct way to use the product, why it must be used in a very specific way and what are the results that can be expected when all this comes together.

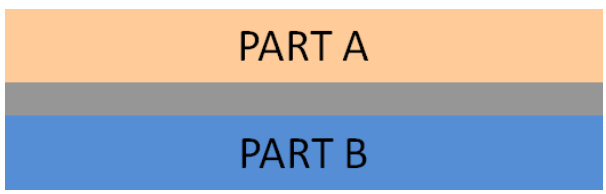
Just one note before we begin-- although the explanations will be long and at times complex, the main message is that high quality products are readily available and their use is indeed very simple, once it is understood how and why they work and minimal training is provided. This is truly a very simple way to connect PVC, CPVC and ABS piping systems with fantastic, consistent results as long as it is done right!

PART 1 – FUSING, NOT GLUING

As a manufacturer of both SC and glues, Weld-On is perhaps in a better position than most to appreciate the difference between the two products. There are of course numerous technical differences between the two families of products but the difference I am referring to here is not the difference in their chemistry but rather the very different way in which they accomplish the same exact thing: bonding two substrates, (part A to part B) which in our case is pipe and fitting.

Before we dive into the difference, why is it important to understand it? It is in fact not only important but essential for specifiers because it needs to influence their choice of product or, more importantly, convince them of the importance of not leaving the choice of SC to the contractor. It is also essential for the Contractors so that they will almost instinctively use the product correctly.

A glue or an adhesive works by bonding itself to part A on one side and to part B on the other side (see picture below), in essence it works as a bridge.



If the two components are in actual contact with each other, there would be no glue left in between them and therefore no bond (remember the bond is only with the glue).

By contrast, a solvent cement does not work well, if at all, when there is actually a space between part A and part B. The reason for this is that 80% of the bond strength that can be achieved with a SC comes by **fusing** part A **into** part B. A simplified depiction of a successful solvent welding looks like this:

The obvious observation in the case of a solvent weld is that the two substrates have now 'flown' into each other but what is not so obvious is that there is nothing between them. Did we not use SC? Where is it?

The fact is that some of the components (the solvents) in a SC are designed to penetrate, melt and/or swell (depending on the solvent – more about this later) the material and then evaporate completely thus allowing the substrates to regain crystallinity and with it all of their physical properties. However, *with the addition of some pressure pushing part A into part B*, now they are one solid block!

‘Connecting’ the above statement to the actual applications of a SC, it is now clear that:

1. The installer cannot just *deposit* the SC on the surfaces (as if it was a glue) but rather needs to *work them into the material.*

2. Somehow we must find a way to generate radial pressure so that the pipe OD on socket ID compress against each other.

PART 2 – CHEMICAL COMPOSITION OF SC

It is possible to discuss the make-up of SC without revealing any proprietary information; this is fortunate because such discussion will lead to yet more understanding of these products and how they rally work.

Actually the name itself (Solvent Cement) gives us the first very important clue; these products have two parts (the solvents and the cement) which, by design, will perform two very different yet essential functions.

SOLVENTS

True Solvents

We have already briefly mentioned that the solvents will soften or swell the pipe and fitting material but what we didn’t say is that certain solvents are also necessary to actually dissolve PVC or CPVC resin. These are referred to as ‘true solvents’ and because of their very aggressive nature will also penetrate deeper into the pipe and fitting wall. While a very deep penetration of the pipe and fitting wall is not always the most desirable thing (depending on factors such as wall thickness, installation temperature, etc.) when appropriate it is easy to illustrate the difference between deep or shallow solvent penetration. Assume that our true solvent and its percentage in the cement is a nail that we are using to put together two pieces of wood. The cement with a greater concentration of true solvents is depicted by figure on the left below, while a cement with a smaller concentration of the same solvent is depicted on the right. Both penetrate the two boards enough to initially hold them together; this can be equated to both cements meeting the ASTM performance standard. But now take each pair of nailed boards and start to wiggle them–this is equivalent to the mechanical loads that your piping system will undergo through its life as the material ages.

Which assembly do you think will come apart first? Obviously, the one with the shorter nail (lesser penetration).

Boiling Point

Some solvents are also included in the cement formulation for their high boiling point which slows down their evaporation. This is a good feature for large diameter systems or very hot weather installations but not so desirable for small diameter jobs where a quick cure time is needed or in very cold weather applications.

Swelling

We have also seen how certain solvents will swell the material. This is important for two reasons:(1) it will make the surfaces more porous, allowing deeper penetration of the solvents and (2) it will increase the interference between pipe and fittings, which is essential to creating that radial pressure which will in turn force material from the two components to mix *with* and *into* each other. These create that lock and that single thicker substrate to which we previously referred.

Lubrication

In a roundabout way, solvents also act as lubricants. This is important to allow the absolutely essential *full penetration* of the pipe into the fitting socket in any interference-fit connection (a highly desirable condition we will further analyze later). I say 'in a roundabout way' because the solvents don't really lubricate anything but create conditions the results of which is similar to lubrication. In these circumstances, it would require incredible force to push the pipe all the way to the stop of the fitting in an interference-fit type joint, which would surely damage either the pipe or the fitting or both. However, after the solvent have been worked into the surfaces, a percentage (if we did this right approx. 1/3 of the wall thickness) of the pipe OD and socket ID will be mollified thus offering little resistance when pushed together: they will simply 'mix'.

Solvent Welding

In the end the right combination and proportion of solvents (accompanied by radial pressure) is what really fuses or welds the pipe and fitting together. *This is a true weld.* Think about this for a second--what are the conditions necessary for what we normally think of as a weld? We need heat to *melt* the parts, and we need *pressure* so that they flow into each other. We are performing a chemical weld, meaning that we are achieving our melt with chemicals rather than heat, and when we add some pressure --voila`! The fact is that if it were possible to eliminate ± tolerances in plastic pipe and fittings we could probably get away with just Solvents and no or little need for Cement.

CEMENT

But we do have tolerances and in molded (fittings, valves) and extruded (pipe) plastic it is basically impossible to have perfect dimensions. In addition, in North America we use tapered sockets. That means that while we hope to always have interference at the bottom of the socket, we will always have a gap towards the mouth of the fitting and sometimes even at the bottom. We therefore need to:

1. Fill that gap

2. Fill it with material that has sufficient density to act as a wedge and actually generate some radial pressure even in places where there are gaps

3. Fill it with material which is compatible with the installation and performance of the operating system

The 'Cement' components in a SC are the ones tasked with performing the three functions listed above, and they are referred to as 'solids'. Much like solvents, there are different materials which are used, each with a different function.

Resin

The first obvious one is resin. This is the same resin that is used for the compounds with which pipe and fittings are made and should have the same cell classification so that they can mechanically, chemically and thermally perform, at the same level that the system will perform. As an example, PVC with a pressure rated cell class should be used in cements sold for use with pressure rated PVC pipe and fittings. With the exception of ABS (which has a much weaker chemical resistance than PVC or CPVC and as such requires weaker solvents) the solvents used in both PVC and CPVC cements are capable of dissolving both resins. This is an important point and means that CPVC cements can be used on PVC systems since the solvents in a CPVC cement will soften and swell PVC and the resin deposited (CPVC) in the interstitial spaces will be able to handle anything that a PVC system can handle (and then some). The opposite however is not true; while the solvents in a PVC SC will soften and swell CPVC, the resin deposited by a PVC cement will not be able to handle the operating parameters of a CPVC system. Therefore in theory we could use CPVC SC in any CPVC or PVC application but it would be an unnecessary expense for PVC systems.

The amount of resin that is used in a SC will vary depending on the gap to be filled and therefore the desired viscosity, but even in Extra Heavy Body SC there is a limit (around 20%). This limit is set by chemistry since it would not be possible (even with only true solvents) to dissolve much more resin than that. We need to remember that this is a solution and once saturated nothing more will dissolve, just like sugar or salt in a cup of water. It is interesting to notice that to meet ASTM a minimum of 10% of homopolymer resin must be used; this means that two manufacturers one using 10% and one using 18% can claim to meet the standard; but is it the same?

Additives & Fillers

But even 20% of resin will not give us the needed viscosity for SC to be used in large diameter systems, so other materials are added. Similar to fillers, additives and stabilizers in pipe and fittings, these materials help with various functions such as increased viscosity, improved stability and shelf life, color differentiation, etc.

SC for chemical applications

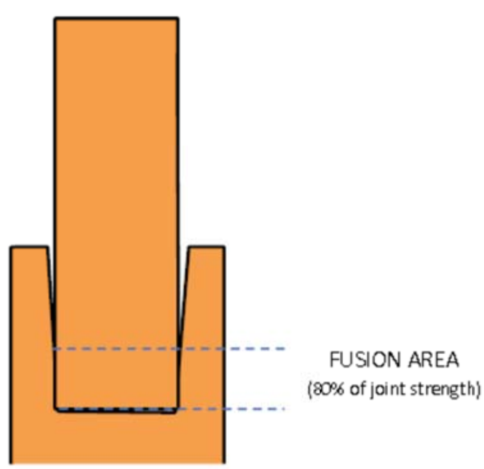
Most of these additives are well known and universally used; however while they may work exceptionally well in many pressure and non-pressure applications, they can be a liability in process or chemical systems. When specifying SC for chemical installation, it is essential to select only products formulated with specialty chemically resistant solid compounds. Remember that if there is a perfect 360° interference between pipe and fitting, they will fuse together around the entire circumference and the only material exposed to the chemical flow will in fact be that of the pipe and fittings (obviously selected to resist the particular chemicals in the line). However, if there is some out of roundness or even a net fit then it is likely the some of the solids will be exposed to the flow as well. If these solids are not chemically resistant, they will corrode and erode over time due to the chemical attack and create a leak path. This is so common in application such as water treatment that some engineers require the back welding of every PVC or CPVC fitting. This is a double-silly move because (a) a back weld performed with a hot air gun (nobody would use an extruder to back weld) has no more than 5psi of pressure rating, which is far less than any process systems and (b) the real simple and successful solution is specifying the use of a proven, chemically resistant SC.

INSTALLATION

The greatest SC on the planet however will not do a good job if poor quality pipe and fittings are used, they are not prepared correctly and/or the SC is not applied correctly.

Pipe & Fittings

We have already mentioned several times the necessity to have ***radial pressure*** in order for the solvent weld to happen as intended. Different parts of the world deal with this in different ways but in North America our solution is a *tapered* fitting socket. The figure below shows an ideal 'fit' for solvent welding. The pipe OD is slightly larger than the ID of the bottom 1/3 of the fitting socket. This is called **Interference Fit** and is the ideal fit which will provide the best, most consistent results.



There are however two other possible 'fits' that can be encountered:

Net Fit - A snug fit, defined by the dry pipe (before any cement is applied to it) encountering some resistance towards the bottom of the socket but which can still be bottomed out. This is still an acceptable fit which will produce excellent results if the cement application is done properly.

Loose Fit - This should never be used in a solvent cement system. This occurs when the dry pipe encounters no resistance all the way to the stop inside the socket, and it's actually loose.

With the proper application of cement and preparation of the pipe both an Interference Fit and a Net Fit will produce joints that are stronger than the individual components because the interference between pipe and fitting (aided by our solids in a Net Fit) at the bottom of the socket in the *fusion area* will provide that 360° pressure necessary to force material from the pipe into the fitting and from the fitting into the pipe.

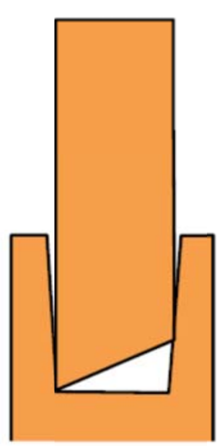
Above the fusion area is the *bond area*, and this is where the solids always play a big role. While only 20% of the strength of the joint is in this area, it is still very important because of the very significant increase of contact area that it provides.

Pipe preparation

It is essential to cut the pipe square since only a square cut will provide the maximum surface area in the fusion part of the joint.

Although an exaggeration, the figure below clearly shows that anything less than a square cut will not only greatly diminish the contact area between pipe an fitting, but it will do so in the lower portion of the socket where 80% of the joint strength is developed.

Burrs and filings can prevent proper contact between pipe and fitting during assembly and must be removed from the outside and the inside of the pipe. Also a slight bevel needs to be placed at the end of the pipe or the sharp edge (made even worse by the raised edge created by the cutting tool) will scrape off the cement from the fusion area as the pipe is inserted.



There are actually three (3) separate reasons for not wanting the removal of cement from this area.

1. Removal of the cement will eliminate the necessary lubrication in the fusion area. This in turn will almost certainly guarantee that the pipe is not fully inserted, thus missing the all-important fusion area.

2. Removal of the cement will also eliminate/shorten the exposure of the fitting wall to the softening agent which together with the radial pressure generated by the proper interference are the only reasons why fusion between pipe and fittings occur. A shortened exposure to the softening agents in the cement will result in a more superficial fusion, the consequence of which will vary greatly from decreased safety factor to shorter life expectancy.

3. If the sharp edges of the pipe remove the cement, where does it go? Only one place – down into the waterway. Lack of a proper bevel is in fact one of the two reasons (the other being over- cementing the fitting socket) why this undesirable condition can occur.

<u>Application of cement</u>

This document does not intend to be an instruction manual so we will glide over many of the details and just provide a flavor of how simple steps are so important to the success of every joint.

After selecting the right cement, attention should be given to the size of the applicator. If too big, there is too much cement is deposited in the socket; if too small, the time to coat the pipe and fitting will be longer than the set time.In other words, the cement starts to harden before a full coat and/or insertion is achieved.

Pipe sizes 1 ¼”and above need to always receive a second cement application on the pipe end. FIRST APPLY CEMENT ON THE PIPE END, THEN IN THE FITTING SOCKET, AND, FINALLY, ON THE PIPE END AGAIN. **This is the brilliant ingenuity of solvent cementing!**

Since we are dealing with pipe and fittings that have ± tolerances, it means that they will always be different. We are also dealing with tapered sockets, which mean that the top, bottom and middle fit/gap between pipe OD and fitting ID is different by design. So how do we make sure that we always use the exact right amount of cement, not too much or too little? We simply apply a generous amount of cement to the pipe, so that whatever gap we will have it will be filled, and a thin coating on the fitting socket so that we achieve softening of the walls but there is simply not enough material to be pushed into the waterway. Whatever excessive material we have deposited on the pipe will be pushed out during pipe insertion so that (a) it is not in the waterway (b) it provides us with a very useful indicator that all gaps have been filled and (c) we can easily wipe off. BRILLIANT!

There are many more details available (e.g. when and how to insert the pipe, set and cure times, solvent welding in either cold or hot conditions, etc.), but again the purpose of this document is to provide the reader with a ‘sense’ of how this *simple* process and products in fact require some very specific knowledge and more attention from the decision makers and specifiers than it usually gets

Fusion welding is indeed a very straight forward, time proven process utilizing products with an astounding success rate. It is also a small expense tasked with a very large responsibility. Choosing the right products and installers who have been trained and understand how to use them is the key to taking full advantage of the many benefits of vinyl piping systems.