Advanced Manufacturing Processes
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Module - 4
Advanced Welding Processes
Lecture - 3
Solid State Welding Processes

Welcome to this course on advanced manufacturing processes, under this course in this session let us discuss about advanced solid state joining process. In the last sessions we have discussed about the résistance welding process and few variants. We have seen the principles of the variant processes, their advantages, limitations and applications. Moving ahead in this session, let us discuss the solid state welding processes namely the ultrasonic welding process and explosive welding process. Let us see their process principles, advantages, features material suitable to be wildered by these processes and potential applications.

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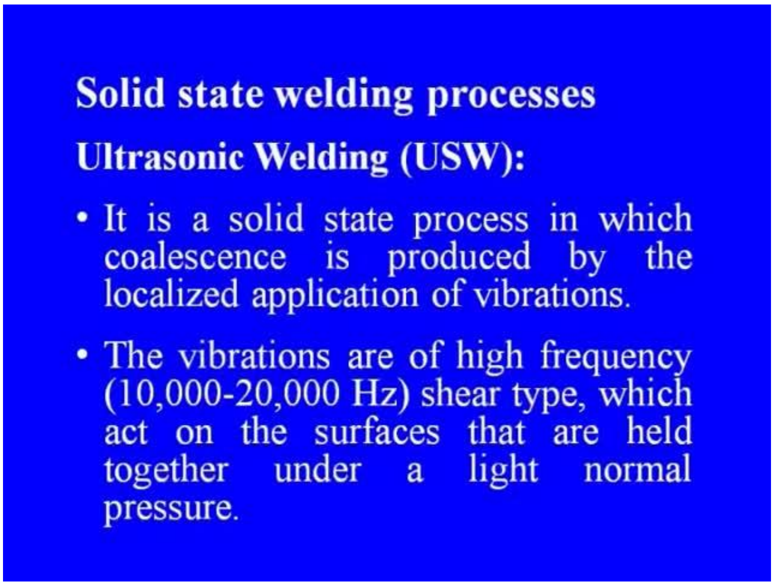

First of all let us study ultrasonic welding processes. Ultrasonic welding process is a solid state process, in which coalescence is produced by the localized application of vibrations. The vibrations are of very high frequency in the order of 10,000 to 20,000 hertz and they are of shear type, which act on the surfaces that are held together under a light normal pressure.

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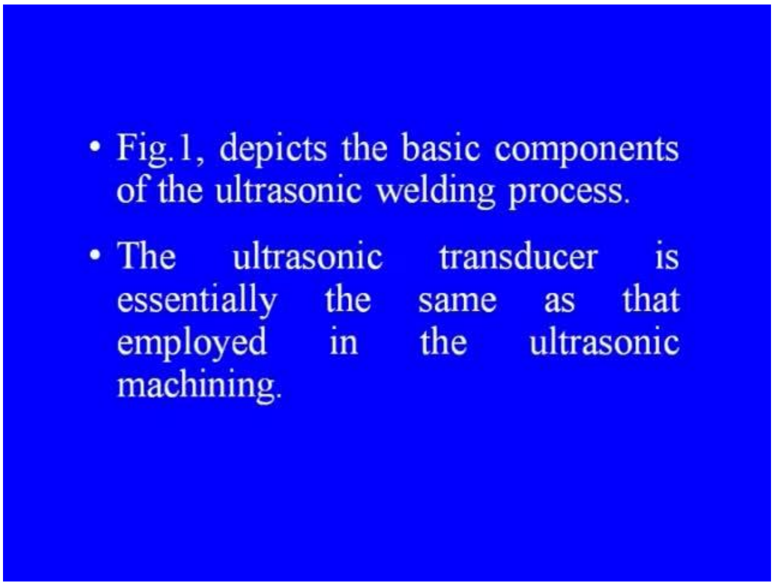

The next figure shows the basic components, and the configuration used in ultrasonic welding process. The ultrasonic transducer is essentially the same as that of employed in ultrasonic machining. We have already discussed one session on ultrasonic machining, in which we have seen about the ultrasonic transducer as well, which is responsible for producing ultrasonic frequencies.

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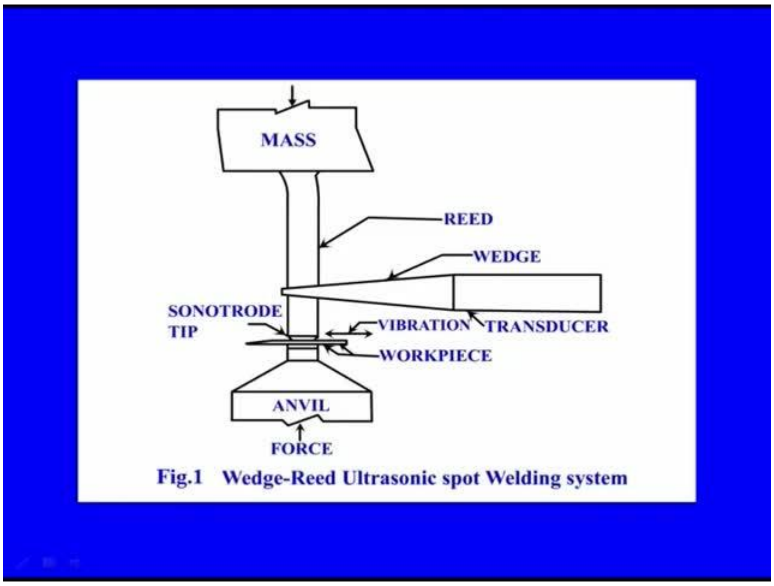

So, this is the configuration used in ultrasonic welding process, which is a solid state process, in which this is the transducer, which is responsible for producing the ultrasonics. These frequencies or the vibrations will be transmitted to the zone of importance through this sonotrode. This zone of interest means the work pieces to be joined or together and there will be a light force applied on to them in addition to these ultrasonic vibrations. So, under the vibration which are of shearing in nature and this light pressure, the materials here in this zone where the sonotrode, will concentrate the ultrasonic vibrations, will get locally heated and get fused.

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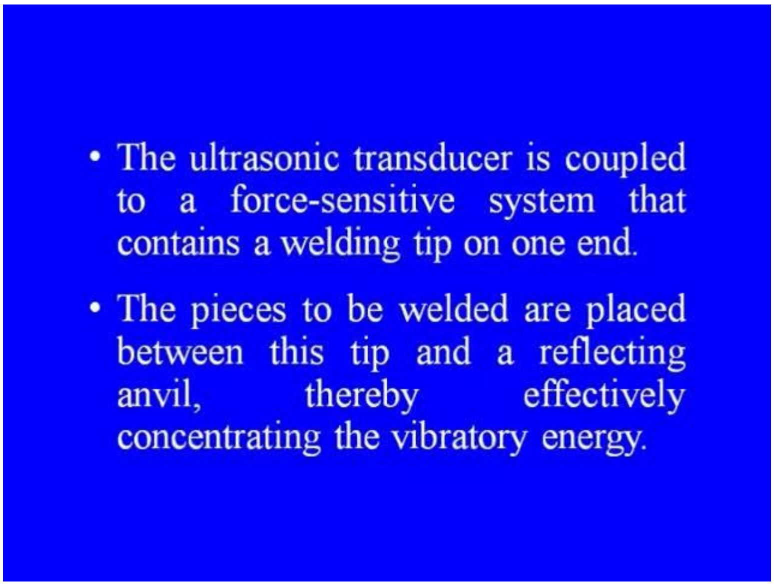

The ultrasonic transducer is coupled to a force sensitive system that contains a welding tip on one end. The pieces to be welded are placed between this tip, and a reflecting anvil, thereby effectively concentrating the vibration energy on to the zone of interest or where the welding is to be carried out.

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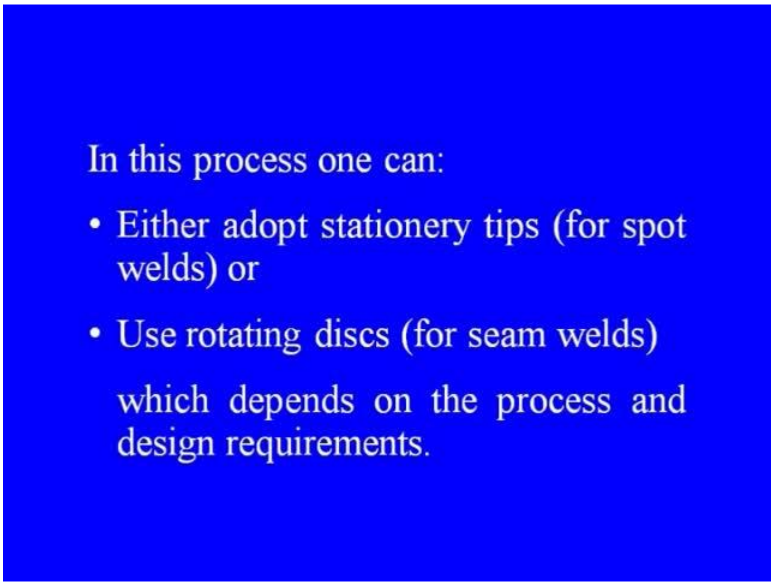

In this process one can either adopt stationary tips for spot welding, as in the spot welding or use rotating discs for seam welds, which depends on the process and design requirements. Now, there are few process variations in this ultrasonic welding process. Basically there are four variations they of this type.

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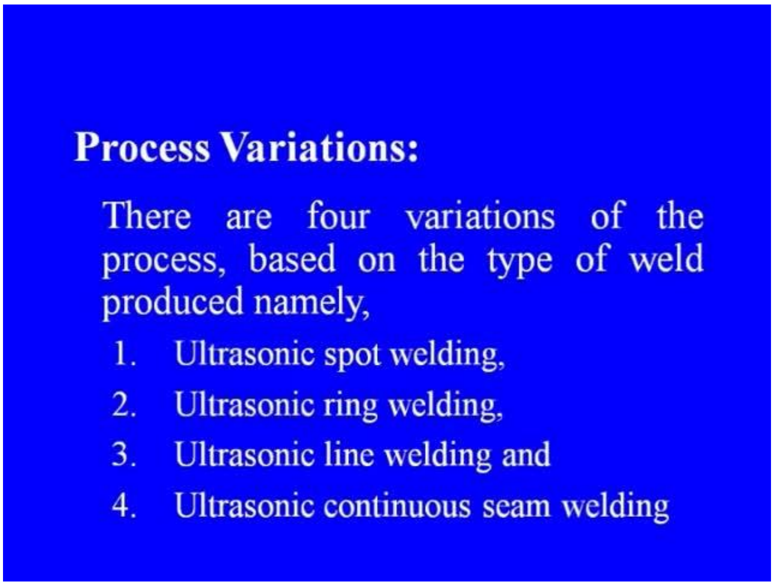

Number one, ultrasonic spot welding, ultrasonic ring welding, ultrasonic line welding and ultrasonic continuous seam welding. Let us first of all discuss ultrasonic spot welding.

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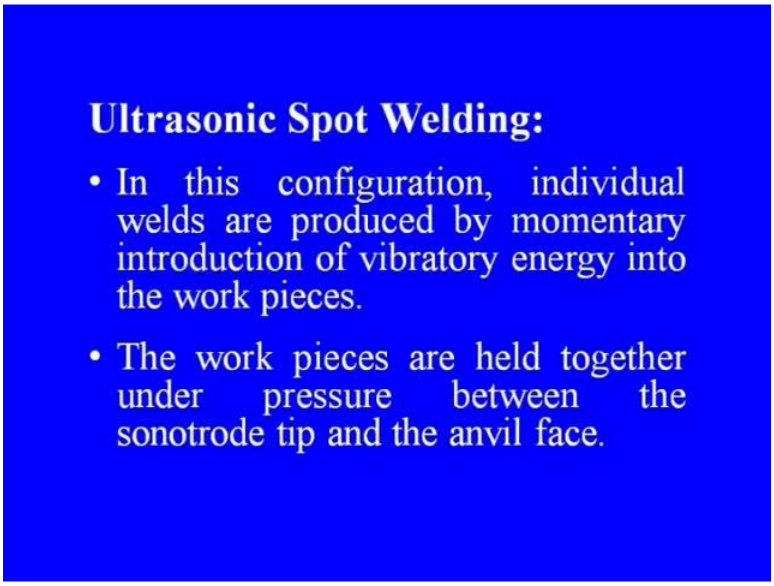

In this configuration, individual welds are produced by momentary introduction of vibratory energy into the work pieces. The work pieces are held together under pressure between the sonotrode tip and the anvil face.

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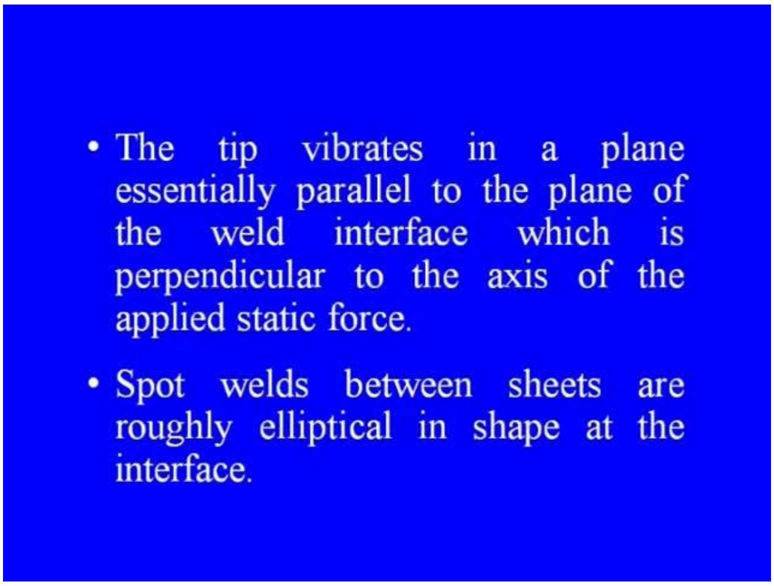

The tip vibrates in a plane essentially parallel to the plane of the weld interface, which is perpendicular to the axis of the applied static force spot welds between sheets are roughly elliptical in shape at the interface.

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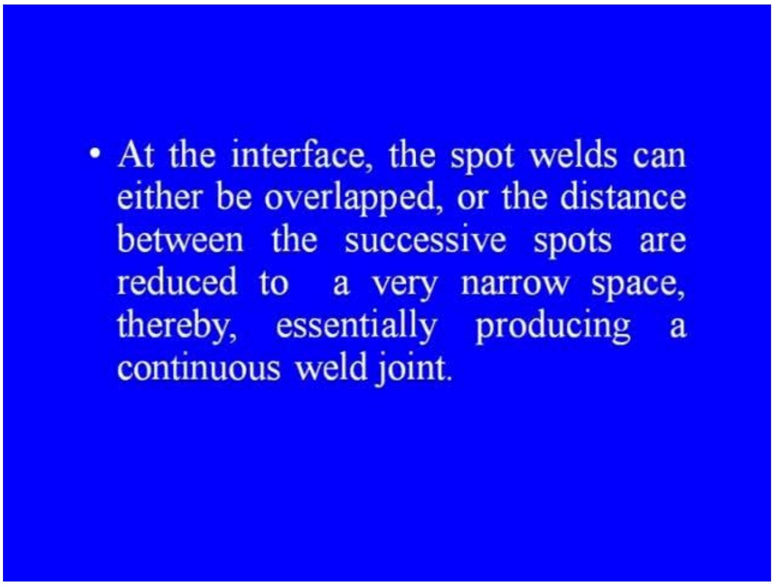

At the interface, the spot welds can either be overlapped or the distance between the successive spots are reduced to a very narrow space, thereby essentially producing a continuous weld joint. Now, let us move on to ring welding.

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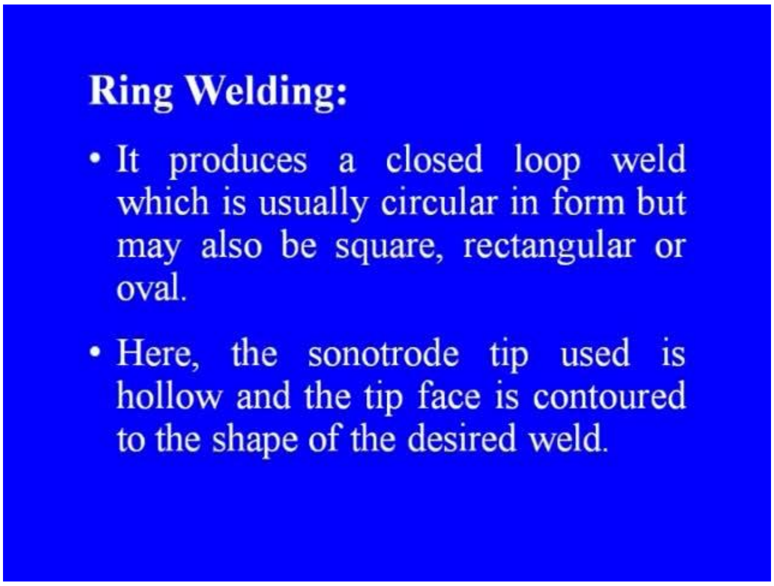

It produces a closed loop weld, which is usually circular in form, but may also be square rectangular or oval here. The sonotrode tip used is hollow and the tip face is contoured to the shape of the desired weld, therefore this means the sonotrode tip.

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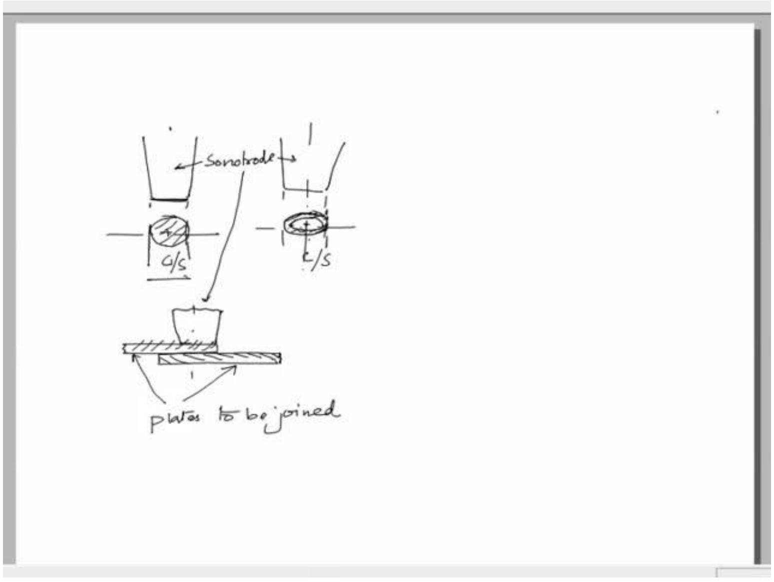

Suppose, if this is the sonotrode being used. Generally this sonotrode will be having a flat place like this, having the cross section like this. Now, in this case the sonotrode can have different shapes, it can be oval like this and it will be generally hollow. Whereas this is entirely solid, therefore the shield or the welding will take place across this or along this solid portion only, wherever there is the solid portion is touching these plates.

Say, let us consider these two plates are being touched by this sonotrode, then the welding will take place on an electrical cross section or the same, that is the shape resembles to the sonotrode shape. This can be, this shape can be even square or some other configuration, as the requirement or the work piece shape demands. So, this is nothing but sonotrode, even this is and this is the cross section of the sonotrode. This is the plates to be joined.

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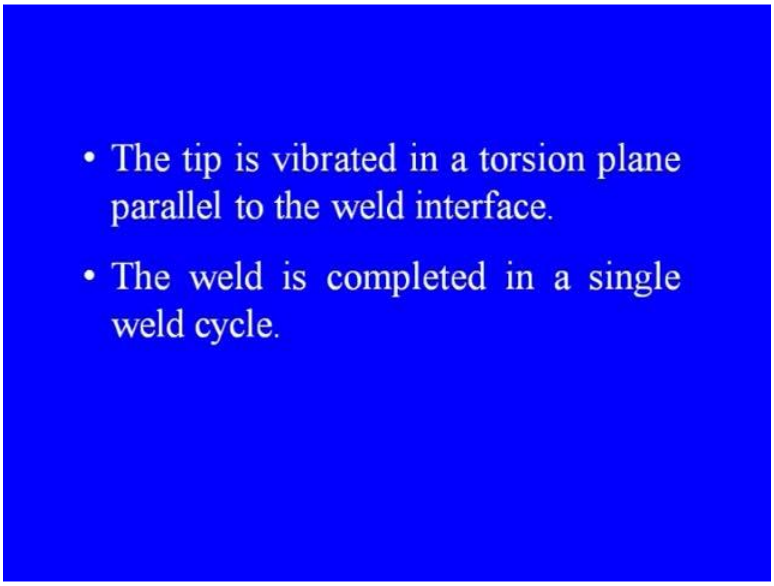

The tip is vibrated in a torsion plane parallel to the weld interface, the weld is completed in a single weld cycle. Now, let us talk about line welding.

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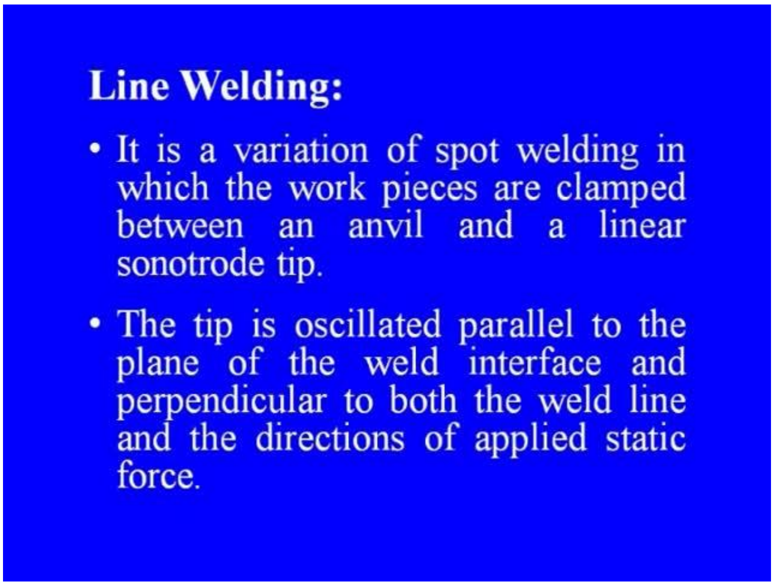

It is a variation of spot welding, in which the work pieces are clamped between an anvil and a linear sonotrode tip. The tip is oscillated parallel to the plane of the weld interface and perpendicular to both the weld line and the directions of applied static force.

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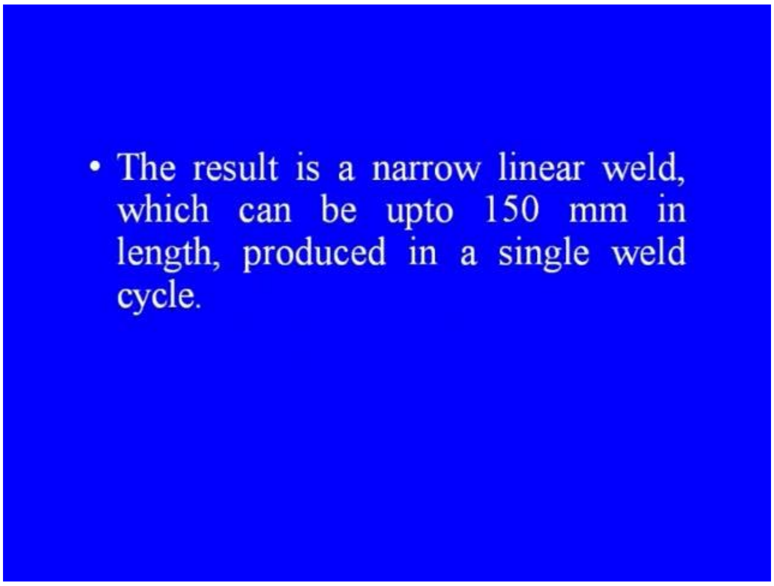

The result is a narrow linear weld, which can be up to 150 millimeter in length produced in a single weld cycle. The next is continuous seam welding, it is a continuous process.

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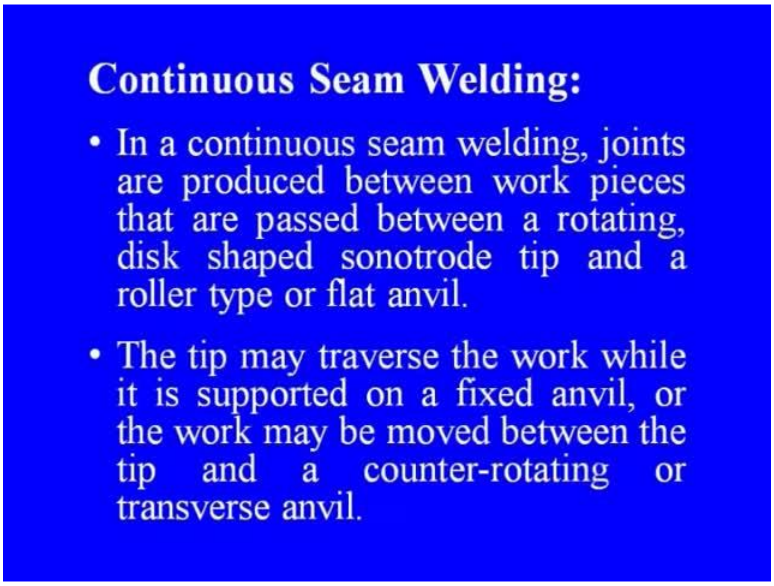

In this process, joints are produced between work pieces that are passed between a rotating disk shaped sonotrode and a roller type flat anvil. The tip may traverse the work while it is supported on a fixed anvil or the work may be moved between the tip and a counter rotating or traverse anvil.

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The advantages of this process are ultrasonic welding has advantages of over resistance spot welding, such that it requires very little heat application during joining without melting of the metal. Consequently no cast nuggets or brittle inter metallics are formed in ultrasonic welded parts.

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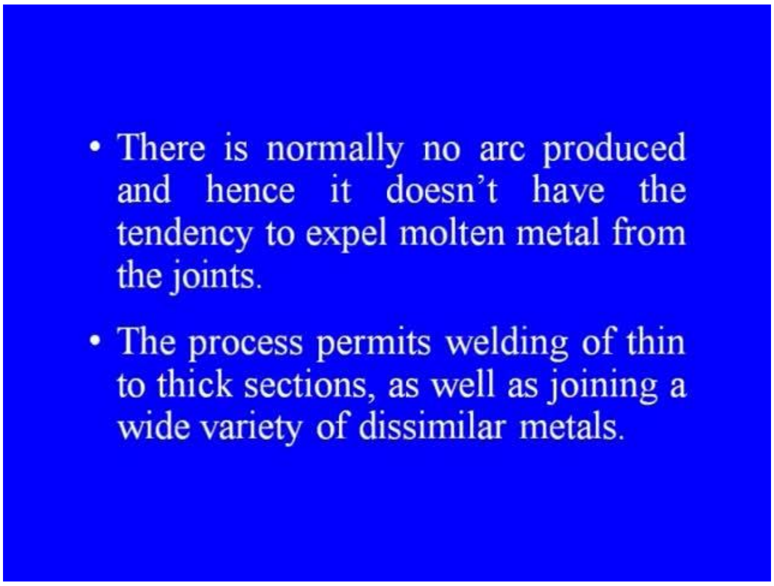

There is normally no arc produced and hence it does not have the tendency to expel molten metal from the joints. The process permits welding of thin to thick sections as well as joining a wide variety of dissimilar metals. The ultrasonic welding of aluminum copper and high thermal conductivity metals require substantially lesser energy as compared to resistance welding. As we have already discussed, while discussing the resistance welding process, particularly in case of high electrically conductive material.

Since, the resistance of the material is less, therefore to compensate for resistance one has to apply higher degree of current to generate the same amount of heat, that is needed for melting and fusion of that material. However, no such conditions are prevalent. In this type of technique, where it does not depend on the resistivity or conductivity of the work material, the pressures used in ultrasonic welding are much lower, this also another advantage of this process, since the pressure requirement is less. Therefore, the fixers to be used need not be very complicated or very, very heavy in construction. The welding time is also much shorter relative to many other welding processes.

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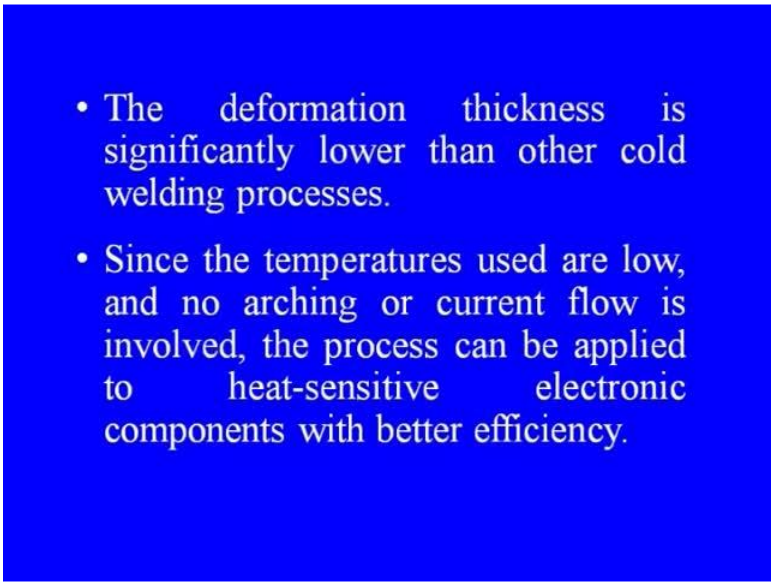

The deformation thickness is significantly lower than other cold welding processes. Since, the temperatures used are low and no arching or current flow is involved, the process can be applied to heat sensitive electronic components with better efficiency for many electronic components. It is essential that the components are not heated beyond a certain limit, otherwise the components inside can get damaged. Therefore, in such cases some conventional thermal based welding techniques, may not be suitable. Wherein which, the heat affected zone get wider and wider. However, in this process ultrasonic welding process, which is essentially not a thermal process, but the heat is generated at a very little localized portion can be very useful for such components.

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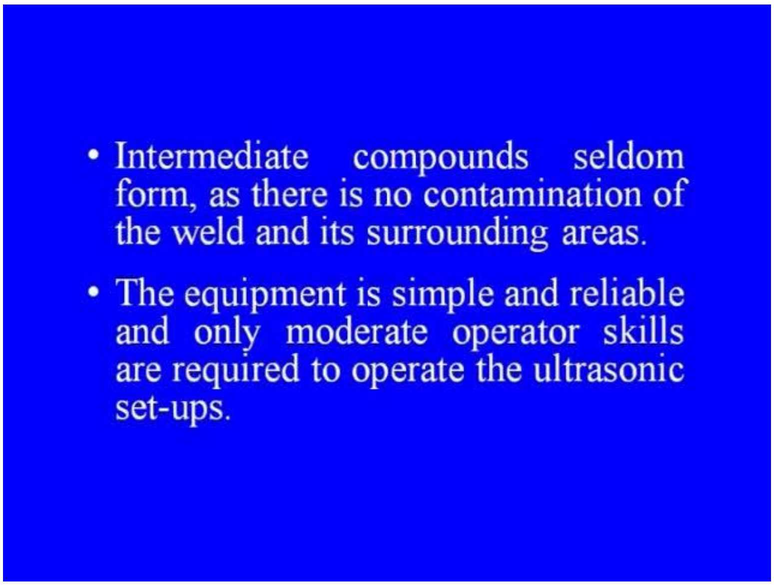

Intermediate compounds seldom form as there is no contamination of the weld under surrounding areas. The equipment is simple and reliable and only moderate operator skills are required to operate the electronic the electronically controlled ultrasonic set ups.

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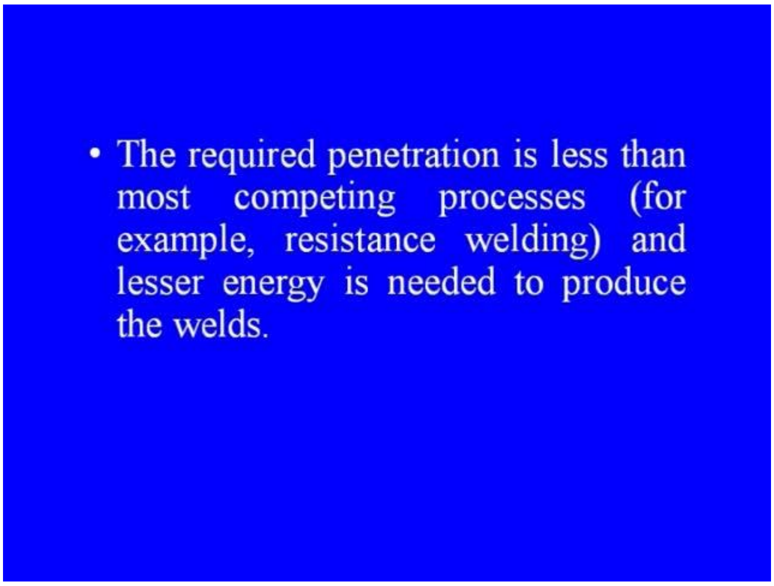

The required penetration is less than most competing processes for example, resistance welding and correspondingly lesser energy is needed to produce the welds. Now, let us identify few disadvantages of this process.

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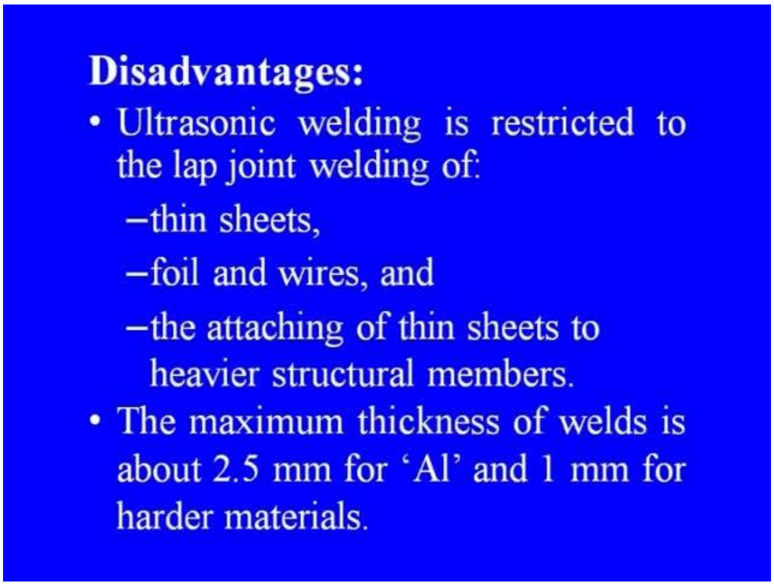

Ultrasonic welding is restricted to the lap joint welding of; thin sheets, foil and wires and the attaching of thin sheets to heavier structural members. The maximum thickness of weld is about 2.5 millimeter for aluminum and about 1 millimeter for harder materials.

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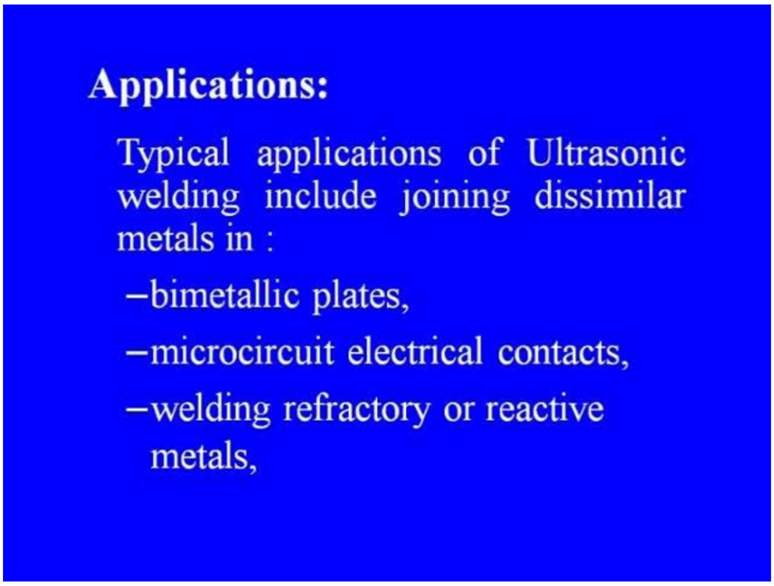

Applications of this process include welding of bimetallic plates, welding of micro circuit electrical contacts, welding of refractory or reactive metals, bonding of ultra thin metals and encapsulating explosives or chemicals.

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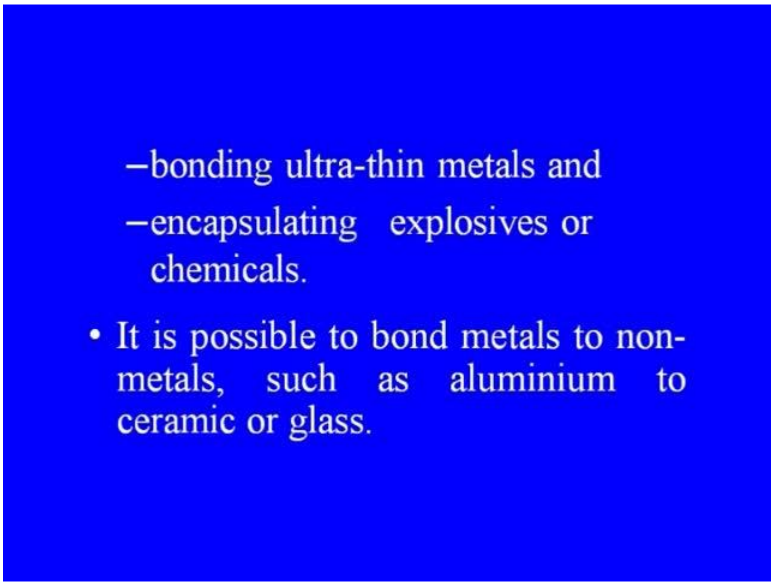

It is also possible to bond metals to non metals such as aluminum to ceramic or glasses. This table as shown in the screen gives an idea about, which are the materials compatible for making this ultrasonic welding. Say for example, aluminum can be welded to aluminum, aluminum can be welded to copper, germanium, gold, molybdenum, nickel platinum, silicon, steal and zirconium.

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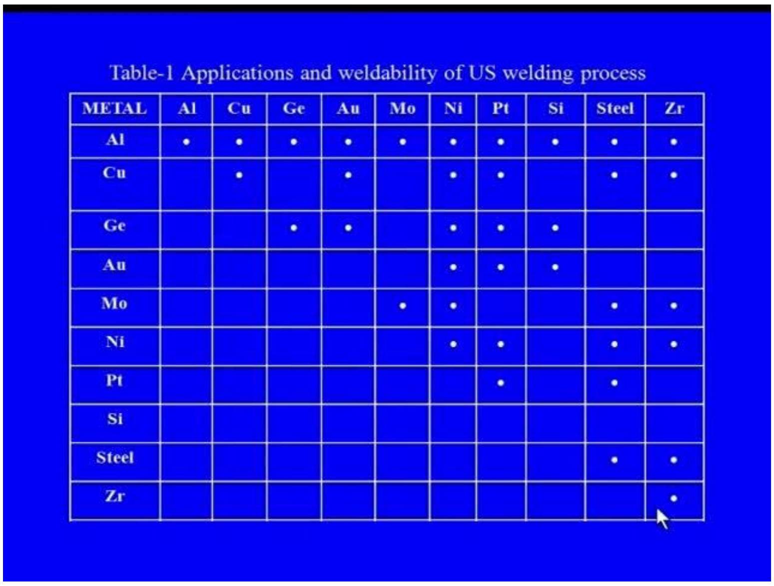
Table-1 Applications and weldability of US welding process

METAL	Al	Cu	Ge	Au	Mo	Ni	Pt	Si	Steel	Zr
Al	•	•	•	•	•	•	•	•	•	•
Cu		•		•		•	•		•	•
Ge			•	•		•	•	•		
Au						•	•	•		
Mo					•	•			•	•
Ni						•	•		•	•
Pt							•		•	
Si										
Steel									•	•
Zr										•

Similarly, copper can be welded to copper as can be seen here not to aluminum or not to germanium, not to molybdenum neither to silicon. Similarly, other metals like germanium, gold, molybdenum, nickel etcetera are also shown against other materials, to whom they can be welded using this particular process. The availability of zirconium is found to be with aluminum copper, then molybdenum nickel and still apart from itself. Now, let us move on to another non conventional and advanced joining method or welding method that is explosive.

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Explosive welding method: This method explosive welding in short also known as EXW is primarily used for bonding sheets of corrosion resistant metal to heavier plates of base metal. Say for example, a cladding operation, particularly when large area are involved. On the other hand we have seen spot welding or the ultrasonic welding are confined to a small relatively small area.

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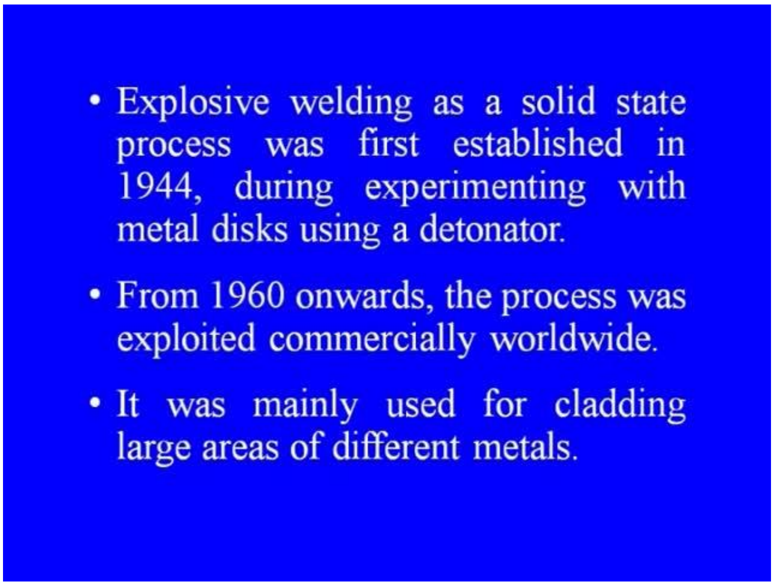

However, this explosive welding is more suited to larger area for bonding. Explosive welding as a solid state process was first established in the year 1944, while experimenting with metal disks using a detonator. From the year nineteen 1960 onwards, the process was exploited commercially worldwide. It was mainly used for cladding large areas of different metals. Let us note about the prerequisites for explosive explosion welding process.

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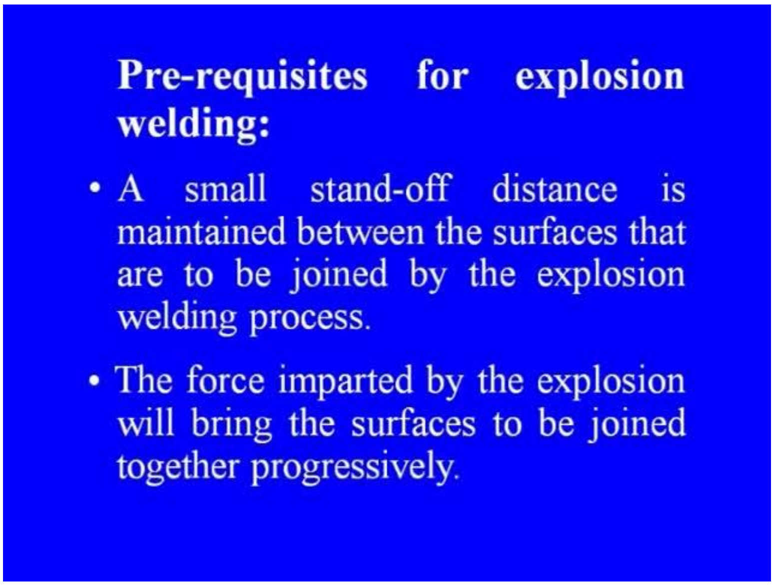

Number one, a small standoff distance is maintained between the surfaces that are to be joined by the explosion welding process. Number two, the force imparted by the explosion will bring the surfaces to be joined together progressively.

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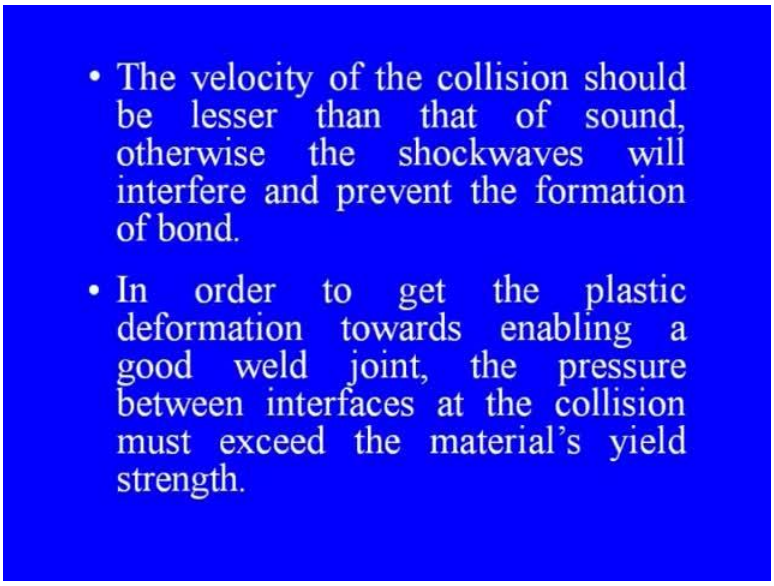

Number three, the velocity of the collision should be lesser than, lesser than that of the sound. Otherwise the shockwaves will interfere and prevent the formation of bond. In order to get the plastic deformation towards enabling a good weld joint, the pressure between interfaces at the collision must exceed the materials yield strength. Now, let us look at the process itself.

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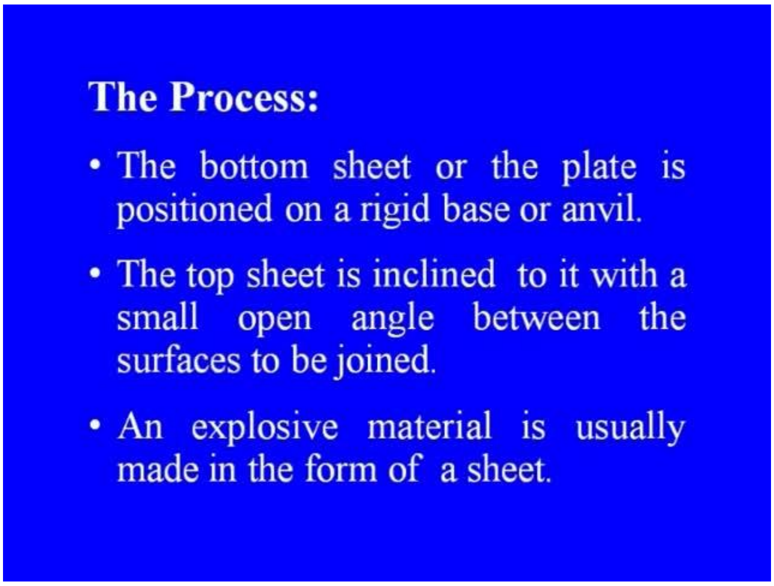

The bottom sheet or the plate is positioned on a rigid base or anvil the top sheet, which is to be welded to the bottom sheet is inclined to it with a small open angle between the surfaces to be joined. An explosive material is usually made in the form of a sheet.

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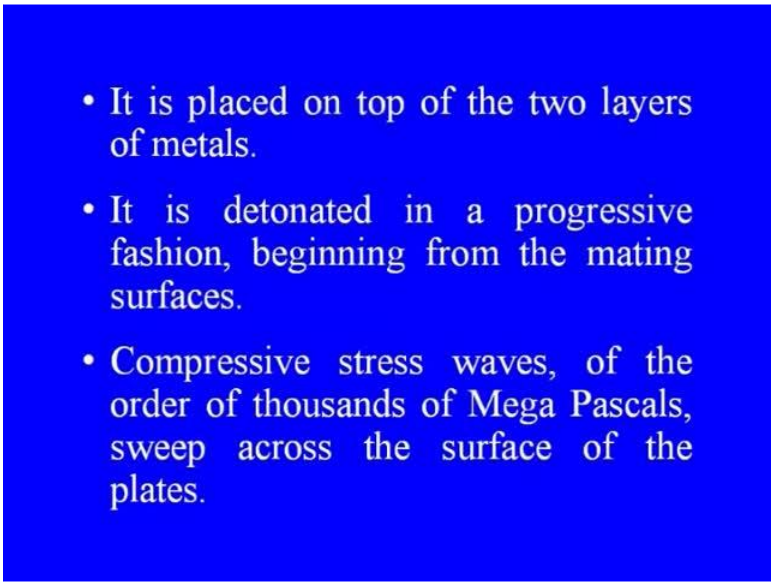

It is placed on top of the two layers of metals. It is detonated in a progressive fashion beginning from the mating surfaces. Compressive stress waves of the order of thousands of mega pascals, sweep across the surfaces of the plates. This can be explained like this.

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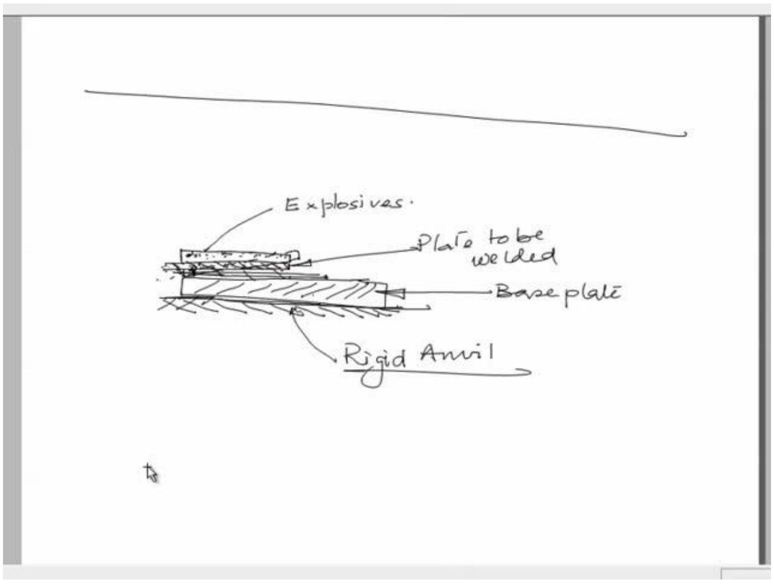

Suppose, this this is the original plate on which another plate say for example, this is to be welded. Now, this original plate of material like this is placed on a fixed anvil fixed anvil or a base. This is the sheet is to be welded on this. Now, on top of this this explosive will be placed in such way that, this can be detonated successively from one end to the other end. So, this is nothing but explosive and this is the plate to be plate to be welded. This is the base plate and this is a rigid, we can say anvil. So, this rigid anvil will be responsible for withstanding the explosive pressure, that will be generated by these explosions.

So, in initial configuration this plate will be placed something like this; that is to some extent inclined on this and then as this explosion takes place. This distance will be minimized, the wave will be the, compressive stresses will be used, will be generated. This will make this weld thin plate to get welded on to this base plate. So, as the successive explosions does take place, so this continuously this plate will come closer to this and ultimately this will form the welded portion like this.

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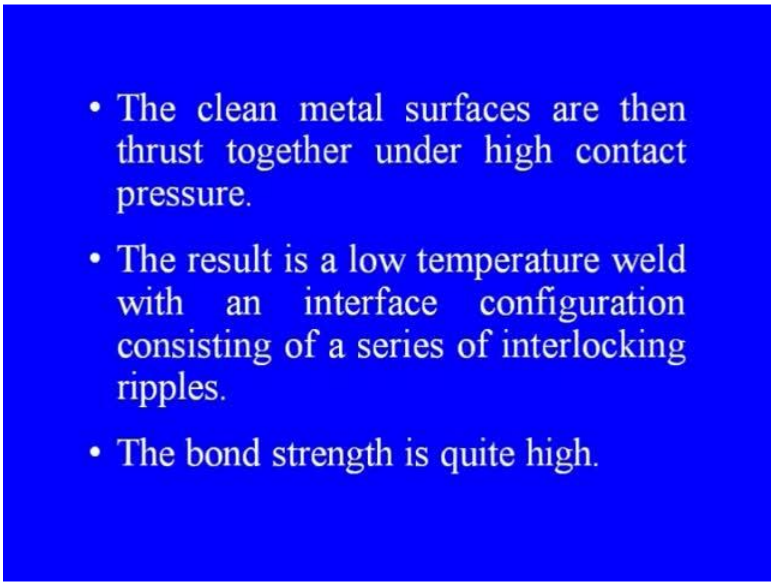

The clean metal surfaces are then thrust together under high contact pressure. The result is a low temperature weld with an interface configuration consisting of a series of interlocking ripples. The bond strength obtained in this welding is quite high.

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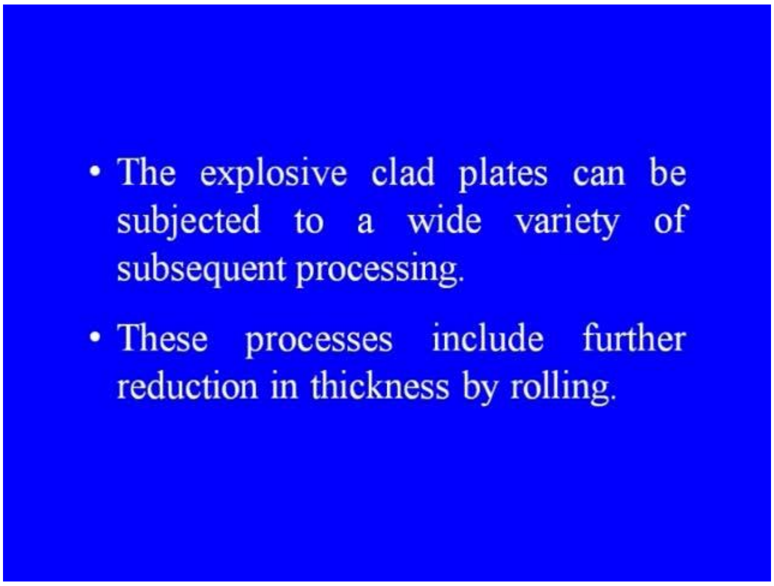

The explosive clad plates can be subjected to a wide variety of subsequent processing this processing, include further reduction in thickness by rolling. In this solid state welding process numerous combinations of dissimilar metals can be joined.

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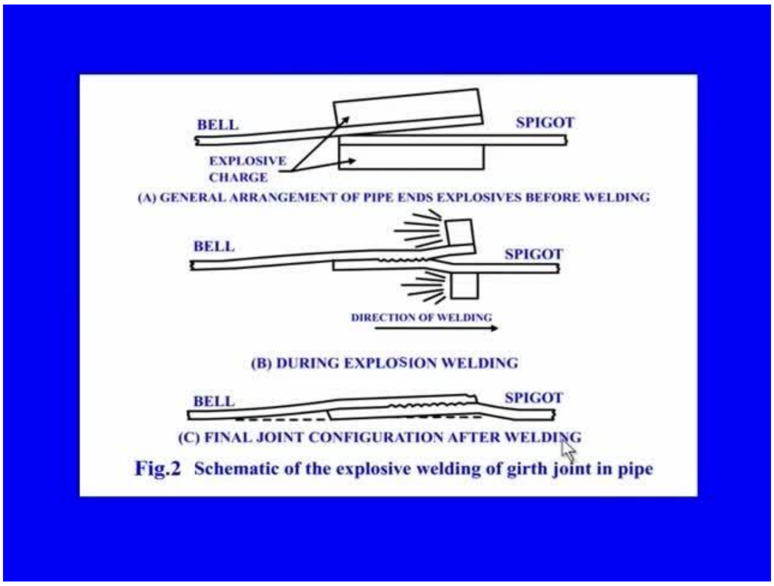

So, this shows the basic configuration of this explosive welding process. This in the screen as can be seen this is the base metal, and this is the another plate to be joined or welded on to this base plate. Now, the explosive will be placed on these two along the length of these plates. Now, continuously the explosions will be caused and because of this the compressive stresses will be developed. They will try to bring these two plates together under a very high stress and this will cause cold welding of these two surfaces. Finally, this will form a joint like this. This joint can further be processed like, it can be rolled again, so that there will be better uniformity obtained or can be heat treated or and so on as per the requirement of the joint.

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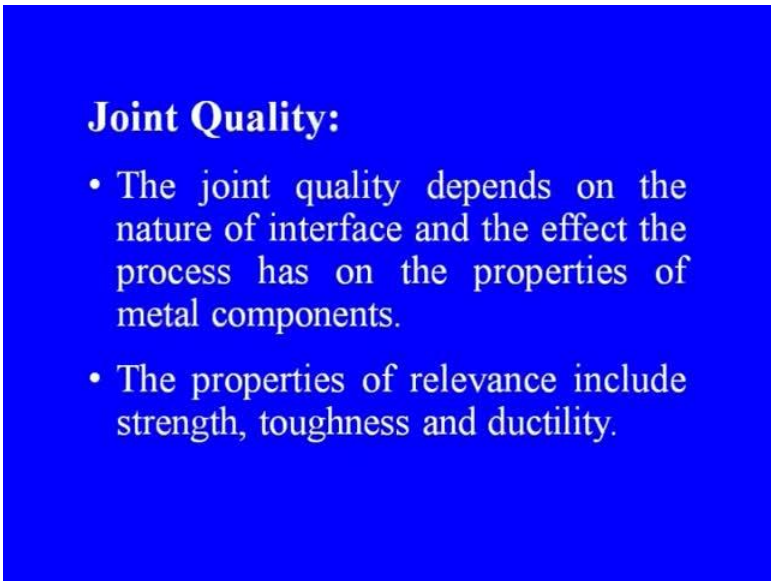

The joint quality depends on the nature of the interface and the effect the process on the properties of the metal components. The properties of relevance include strength toughness and ductility.

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Using standard ASTM procedures the effect of welding on these properties can be determined. Further the result of tension impact bending and fatigue tests of welded and un welded materials can be compared. Now, let us note the benefits of explosive welding process over other processes.

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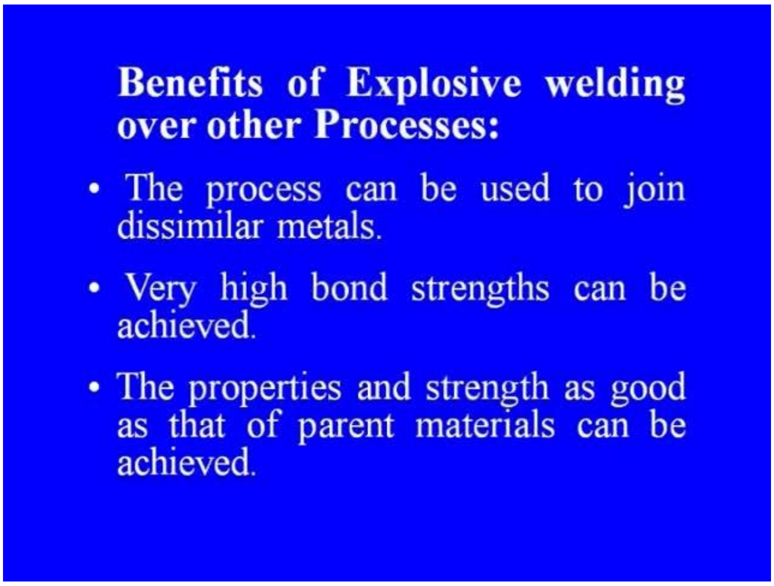

This process can be used to join dissimilar metals. Very high bond strengths can be achieved, then the properties and strength as good as that of parent materials can be achieved. Large surface areas can be joined or welded, this is clearly another advantage like two sheets of paper or two sheets of metal mostly in the metal if are to be joined, then the conventional processes it is very difficult or time consuming. However, by application of explosion welding process, they can be joined very easily at low cost.

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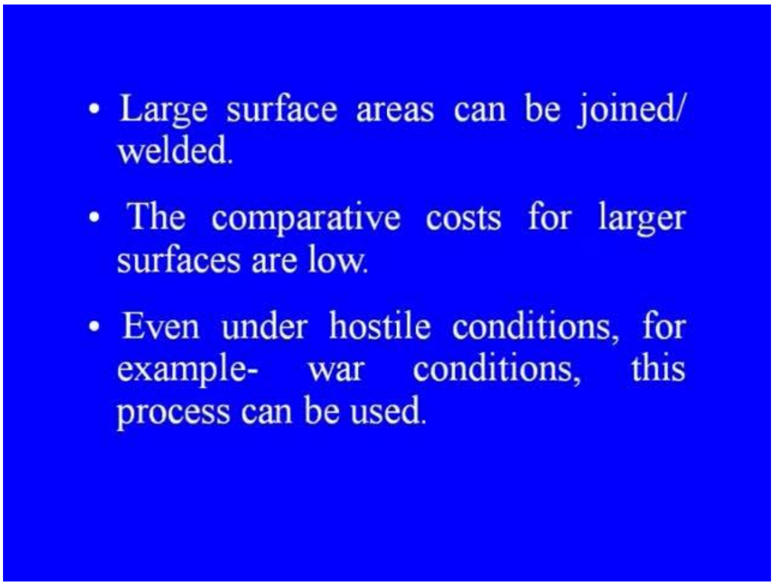

Even under hostile conditions for example, war condition where we may not have adequate equipment for other kind of welding, this joining technique can be readily used.

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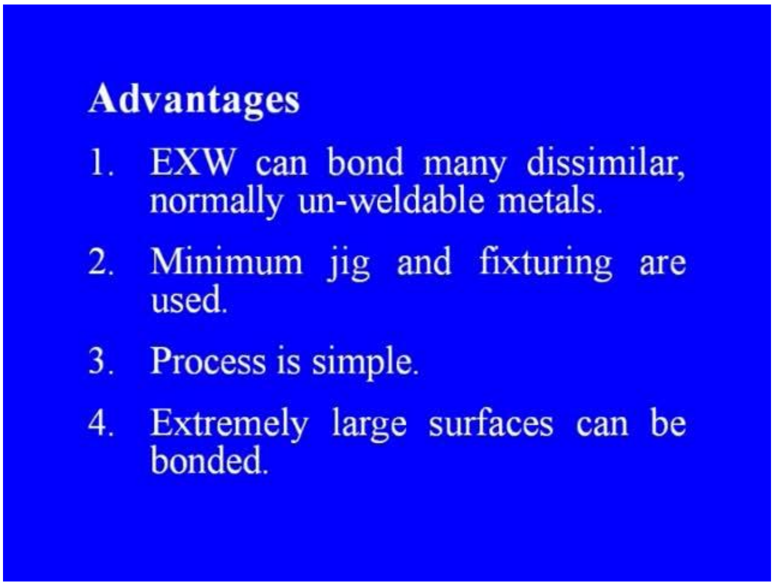

The advantages of this process include it can bond many dissimilar or normally un weldable metals. minimum jig and fixtures are required in this process. The process is essentially very simple and extremely large surfaces can be bonded which is clearly an advantage.

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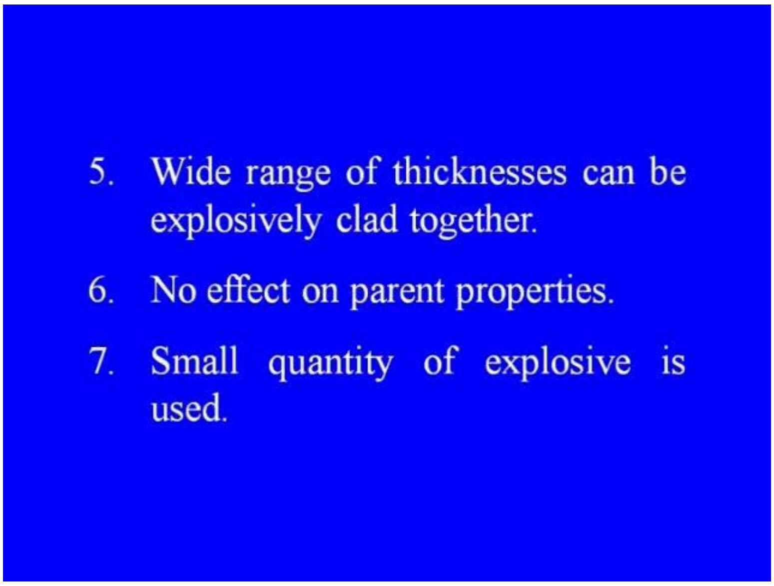

Wide range of thicknesses can be explosively clad together. No effect on parent properties can be observed because there is hardly any thermal effect involve on this and therefore, the parent material properties remain intact, which is very, very significant because we have already seen in few other processes, where heat effected zones are formed. Then along with that heat effected zones the material properties or the parent material properties get changed, which may not be desirable in many cases. Of course, the quantity of explosives required may not be very high. However, there are few limitations as well of the process.

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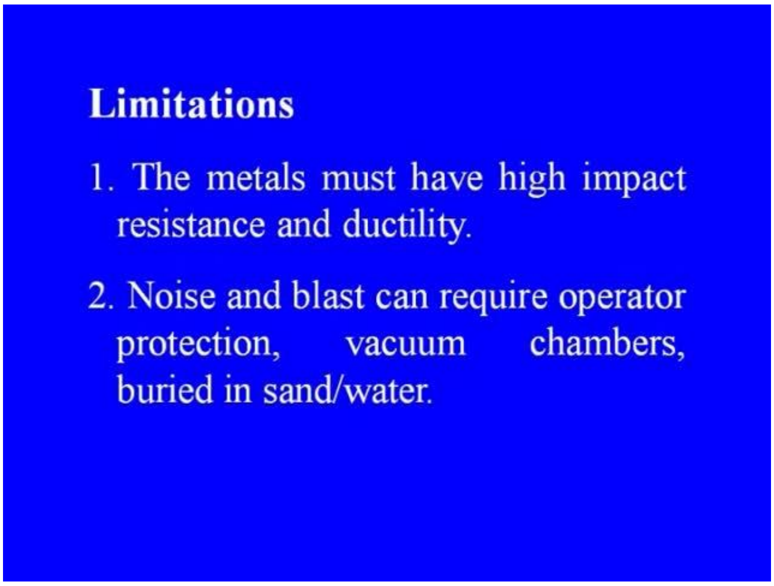

This limitation include the metals must have high impact resistance and ductility. Mostly the brutal materials cannot be joined in this process because they may get cracked. Therefore, ductility is a property, which is considered almost prerequisite for this for the materials to be joined using this process. Noise and blast can require operator protection vacuum chambers or the process, entire process should be carried out in a buried condition or under water condition.

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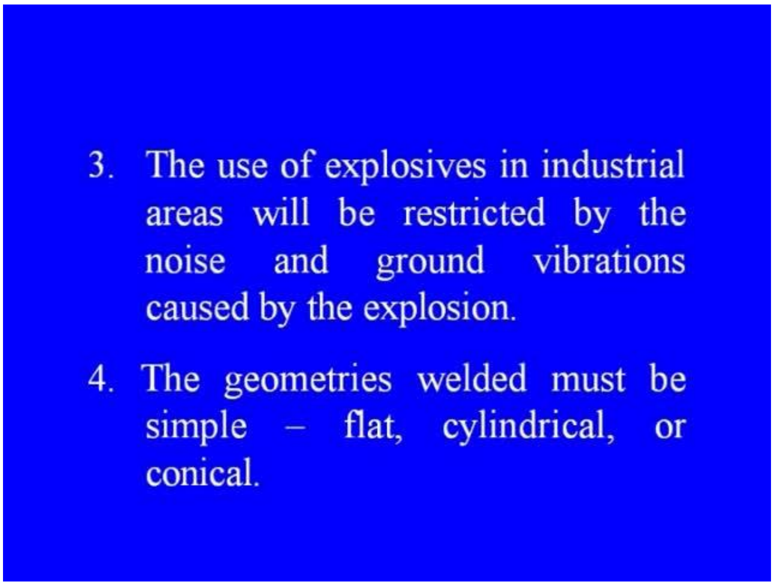

The use of explosives in industrial areas will be restricted by the noise and ground vibrations caused by the explosion. It can cause safety hazards the geometries welded must be simple generally a flat cylindrical or conical geometries are possible. In this process some intricate geometries may not be possible or even if one gets it, the result may not be as per expected. Now, let us see different features and applications of this process explosive welding process.

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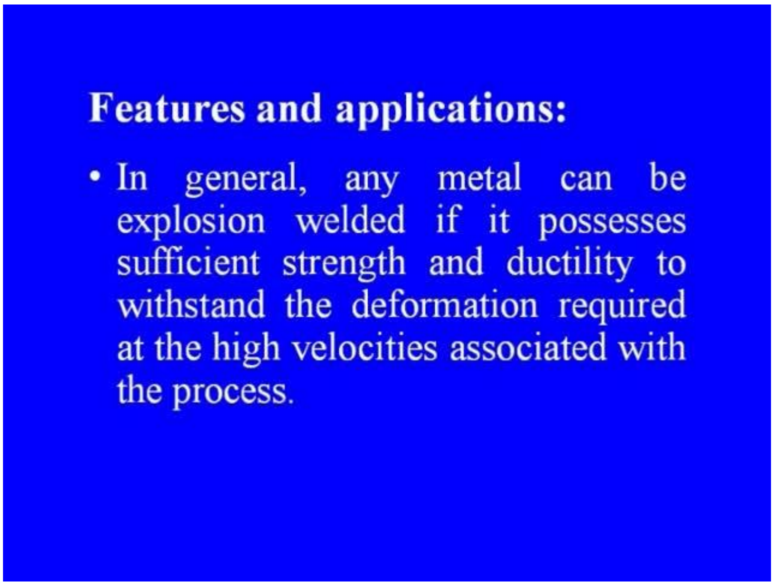

In general any metal can be explosion welded if it possesses sufficient strength and ductility to withstand the deformation required at the high velocities associated with the process.

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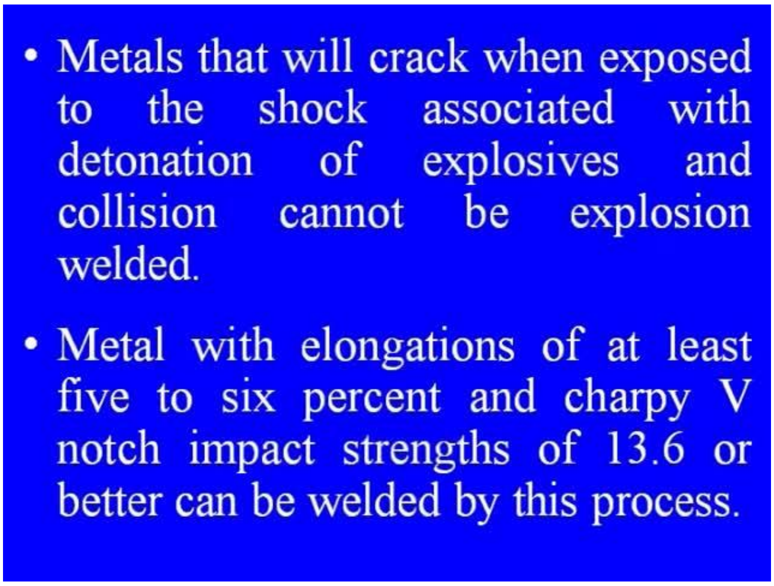

Metals that will crack when exposed to the shock associated with the detonation of explosives and collision cannot be explosion welded. Metal with elongations of at least five to six percent and charpy v notch impact strength of 13.6 or better can be welded by this process.

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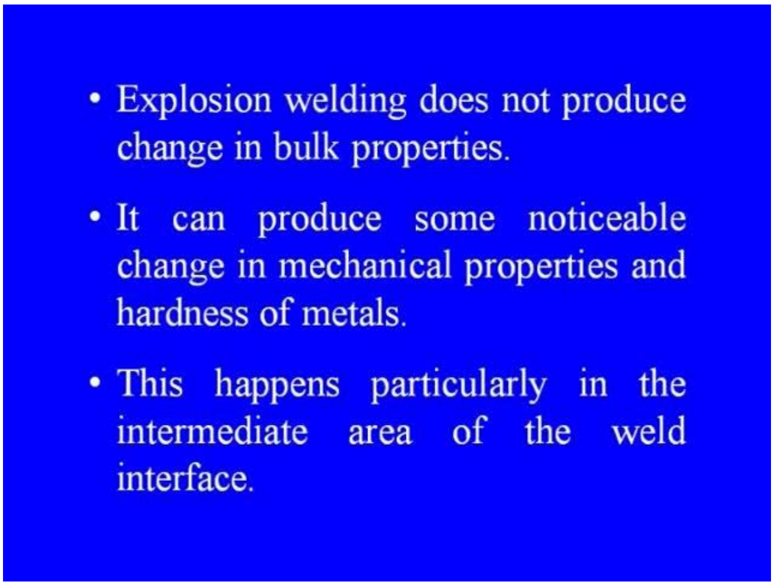

Explosion welding does not produce change in bulk properties. It can produce some noticeable change in mechanical properties and hardness of metals. This happens particularly in the intermediate area of the weld interface.

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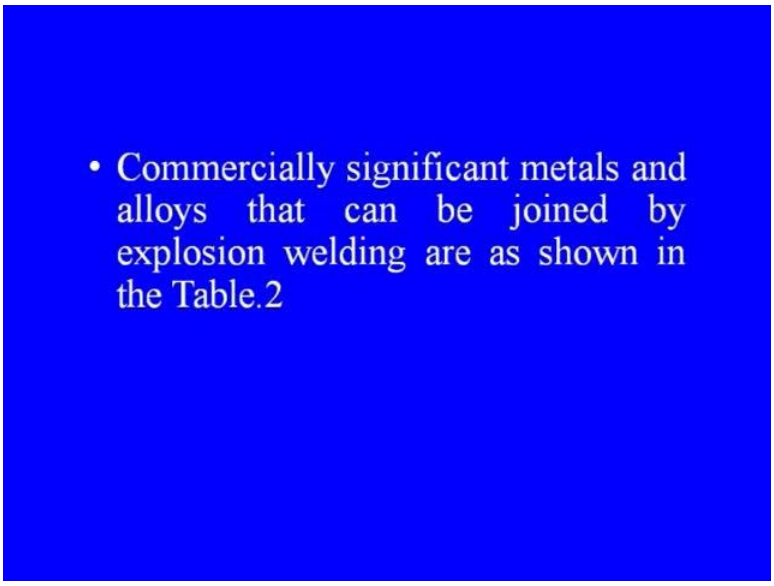

Commercially significant metals and alloys that can be joined by explosion welding are shown in this table. This is shown in the screen.

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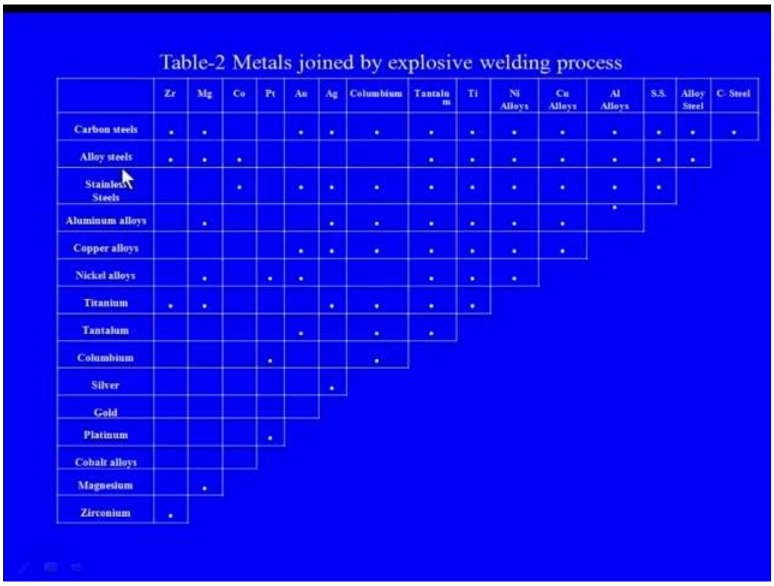

Table-2 Metals joined by explosive welding process

	Zr	Mg	Co	Pt	Au	Ag	Columbium	Tantalum	Ti	Ni Alloys	Cu Alloys	Al Alloys	S.S.	Alloy Steel	C- Steel
Carbon steels	•	•			•	•	•	•	•	•	•	•	•	•	•
Alloy steels	•	•	•					•	•	•	•	•	•	•	
Stainless Steels			•		•	•	•	•	•	•	•	•	•		
Aluminum alloys		•				•	•	•	•	•	•	•			
Copper alloys					•	•	•	•	•	•	•				
Nickel alloys		•		•	•			•	•	•					
Titanium	•	•				•	•	•	•						
Tantalum					•		•	•							
Columbium				•			•								
Silver						•									
Gold															
Platinum				•											
Cobalt alloys															
Magnesium		•													
Zirconium	•														

Different materials like carbon, steels, alloy steels, stainless steels, aluminum alloys, copper alloys, nickel alloys, titanium, tantalum etcetera are shown again the materials with whom they can be explosion welded. In most of the cases they themselves can be welded. Say for example, titanium can be welded to tantalum and titanium itself, but in some cases say for example, nickel alloys may not form a very good explosion welding joint with material like cobalt or Colombia. Therefore, few restrictions are there, apart from these restrictions most of the materials or alloys can be welded each other using this explosive welding process. Now, let us look at the product applications of this explosive welding process.

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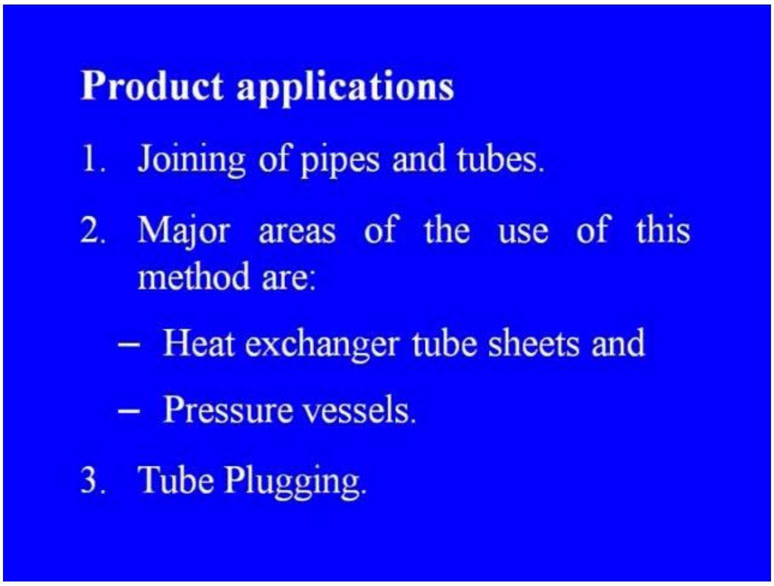

Joining of pipes and tubes can be very easily carried out using this explosive welding process. Major areas of the use of this method are heat exchanger tube sheets and pressure vessels tube plugging.

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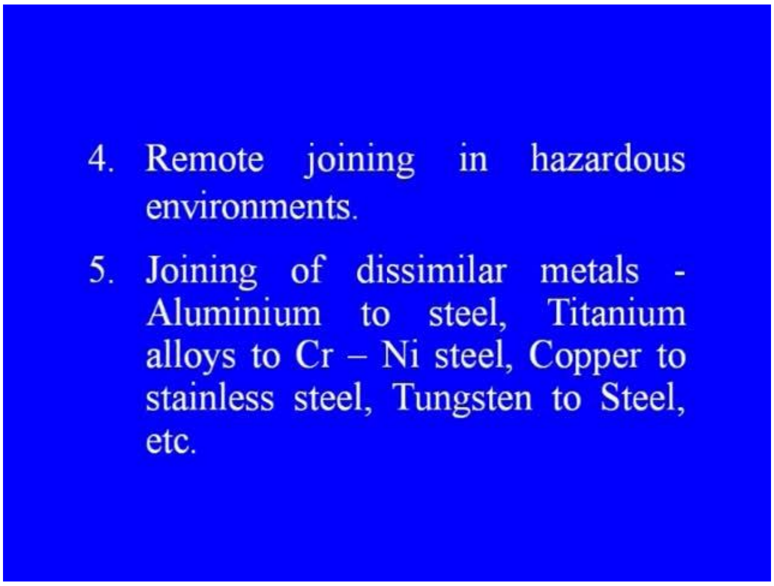

Remote joining in hazardous environments. Joining of dissimilar metals say for example, aluminum to steel titanium alloys to chromium nickel steel copper to stainless steel tungsten to steel etcetera, etcetera.

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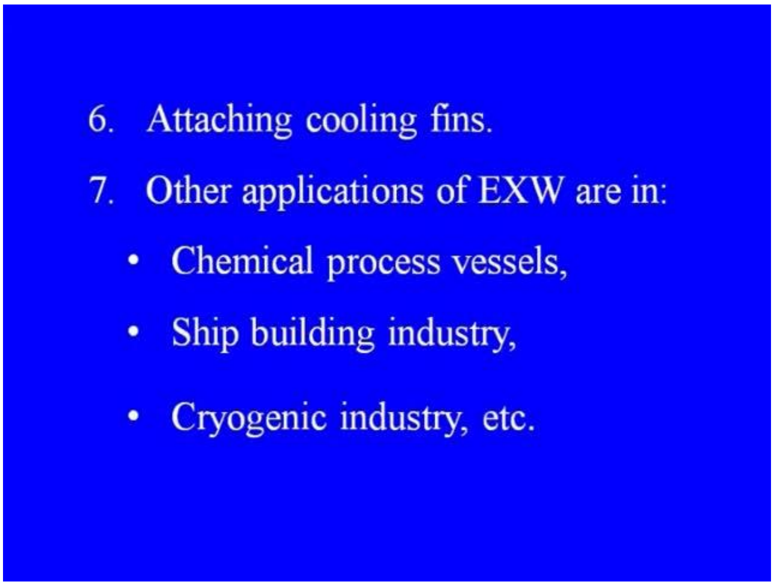

Attaching cooling fans, this is another significant application other applications of explosive welding are chemical process vessels, which are essentially big ones. As we have already discussed, this process is particularly suitable for large area bondings or weldings ship building industries, in which also large sheets are to be welded or joined together, then in cryogenic industries etcetera. Now let us summarize what we have discussed in this particular session. In this session, we have discussed about the solid state welding processes namely the ultrasonic and explosive welding processes.

The principles of working of ultrasonic process and explosive welding processes have been discussed, both are solid state processes and both processes do not have much of the thermal fall outs. That is in both the processes heat effected zones are very, very limited. Applications and features of ultrasonic welding and its variant processes namely the spot welding, line welding and continuous welding, have been discussed. The prerequisites and process features of explosion welding processes have been discussed, in which we have found ductility of the material is an important aspect for the materials to be explosion welded and generally large area are preferred. And the advantages and limitations and applications of this processes, both the processes have been discussed.

In both the cases we have found, that these processes are unconventional in nature and to a great extent they are clean processes, which do not burn any gases, do not produce any arcs and generally do not produce any slags or derbies etcetera. In both the cases basically the energy used is of un conventional in nature. In the first case electrical energy is used for producing the ultrasonic waves or the frequencies, in the later case that is in the explosion welding the energy is produced by means of exploding some explosives, which is designed as per the requirement of the welding process. We hope this session was informative.

Thank you.