Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part- 1

Module- 48

by
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Hello and welcome to this manufacturing process technology part 1 module 48 so we were actually talking about arc welding process.

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Manufacturing Process Technology-Part 1 (Module 48)

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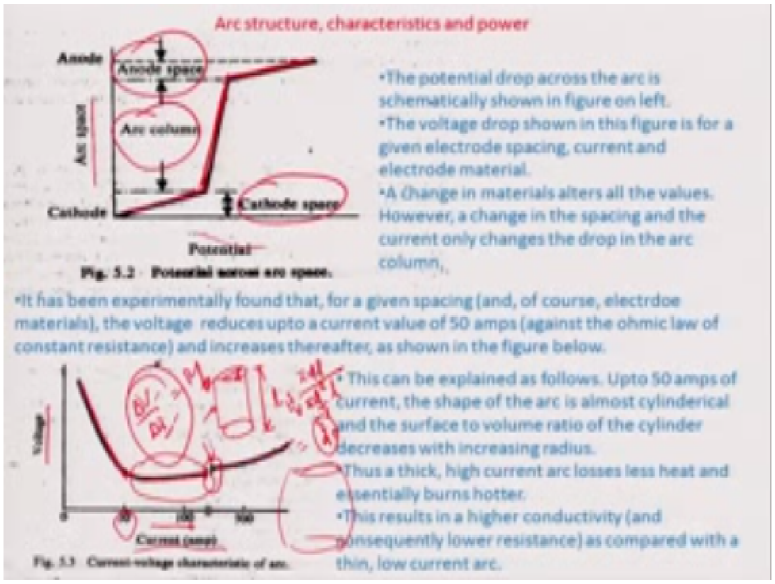

Arc structure, characteristics and power

Fig. 5.2 Potential across arc space.

- The potential drop across the arc is schematically shown in figure on left.
- The voltage drop shown in this figure is for a given electrode spacing, current and electrode material.
- A change in materials alters all the values. However, a change in the spacing and the current only changes the drop in the arc column.
- It has been experimentally found that, for a given spacing (and, of course, electrdoe materials), the voltage reduces upto a current value of 50 amps (against the ohmic law of constant resistance) and increases thereafter, as shown in the figure below.

Fig. 5.3 Current-voltage characteristic of arc.

- This can be explained as follows. Upto 50 amps of current, the shape of the arc is almost cylinderical and the surface to volume ratio of the cylinder decreases with increasing radius.
- Thus a thick, high current arc losses less heat and essentially burns hotter.
- This results in a higher conductivity (and consequently lower resistance) as compared with a thin, low current arc.

As in particularly describing the voltage drop across the arc so we sort as try to find out what is the relationship between the arc space for example this is the cutter space this is the arc column this is anode space and the respective voltage drops where we actually reason out why it takes that the voltage drops produced steep in the areas of column space and anode space.

But it comes to the arc column cannot be that steep and one of the reasons is that basically have shields off opposite irons crossed the electrons and the crystal which has to be penetrated and so there is an energy loss it comes of the cathode or goes into the anode because of the surrounding charges there is an arc column but it is more or less like an resistance component so there is not much which can be done about this thing.

Actually we also talked about the various relationships between the voltage and the cathode for the arcs and it took it out that as the reason doubt that for arc current has less than 50 ampere and so on the arc is more or cylindrical because of which the surface to the volume ratios basically the diameters so the increase in diameter there is a surface area and reduction and the volume decreases.

And because of there is more heat transfer less heat transfers and the arc gets hotter and the conductivity goes up but resist will goes back. where as after 50 amperes there is a amount of current you know over 50 voltage does not change much because obviously the arc starts bulging and there has more path resisted path which happens because of this divergence so there is a sort of balance between the heat up the arc and the bulging because of resistance would increase.

And so one on become an conductivity increases on the other hand the pass alone increases beyond the certain time close to about 200 ampere of current will see that now the dominant factor is basically the bulging out arc and because of the resistivity again increase and there is a beyond relationship which is soluble linear increases.

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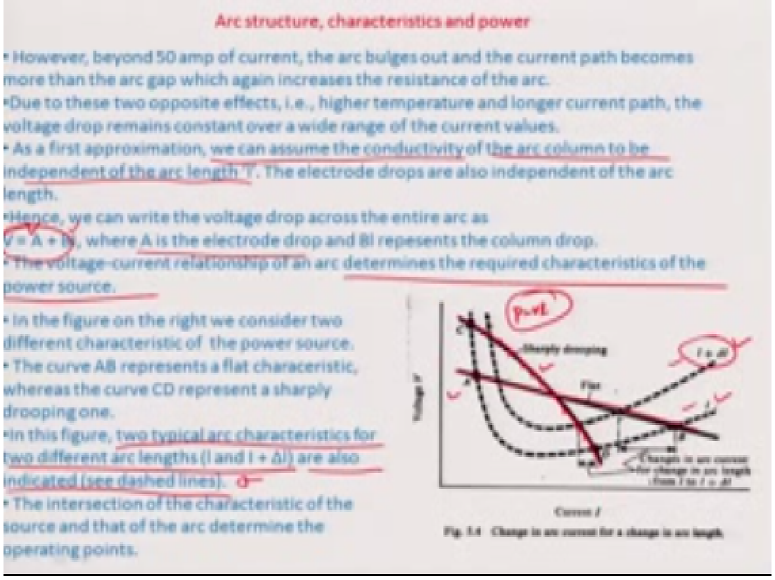

Arc structure, characteristics and power

- However, beyond 50 amp of current, the arc bulges out and the current path becomes more than the arc gap which again increases the resistance of the arc.
- Due to these two opposite effects, i.e., higher temperature and longer current path, the voltage drop remains constant over a wide range of the current values.
- As a first approximation, we can assume the conductivity of the arc column to be independent of the arc length 'l'. The electrode drops are also independent of the arc length.
- Hence, we can write the voltage drop across the entire arc as $V = A + Bl$, where A is the electrode drop and Bl repesents the column drop.
- The voltage-current relationship of an arc determines the required characteristics of the power source.
- In the figure on the right we consider two different characteristic of the power source.
- The curve AB represents a flat characeristic, whereas the curve CD represent a sharply drooping one.
- In this figure, two typical arc characteristics for two different arc lengths (l and l + Δl) are also indicated (see dashed lines).
- The intersection of the characteristic of the source and that of the arc determine the operating points.

Fig. 1.4 Change in arc current for a change in arc length

So that is how we reasoned out how this characteristics of voltage versus current forms so obviously get an different arc lens it would actually have different voltage current characteristics in this particular case for example these are two different characteristics for arc length L and L+ΔL so this is an additional ΔL that the arc for will be the voltage characteristics we can find out the total difference.

For operating characteristics of the power source which is feeding the system is really dependent on the intersection point of the you know relationship of the power source with respectively. arc length characteristics and wherever there are intersection points at the found of operation of the particular arc so as a first approximation we can assume that the conductivity of the arc column is kind of independent of the arc length okay.

But we know that the bulging of the phenomena happens it is later on wherever the length comes into the picture so we can say that V is equal to sum component which is electrode drop component plus VL where this is the length based on drop when the weight age of the length among increases the voltage and this release the electrode drop voltage which is added as the dependent of the length of the arc column.

So the voltage current relationship of an arc determines the required characteristics of the power source from the right we can consider two different characteristics for example this is the linear characteristics as you conceive this is the sharply characteristics so power as you know is VI so therefore everything and this sharply determines characteristics is basically the ER relationship when the power source could be high.

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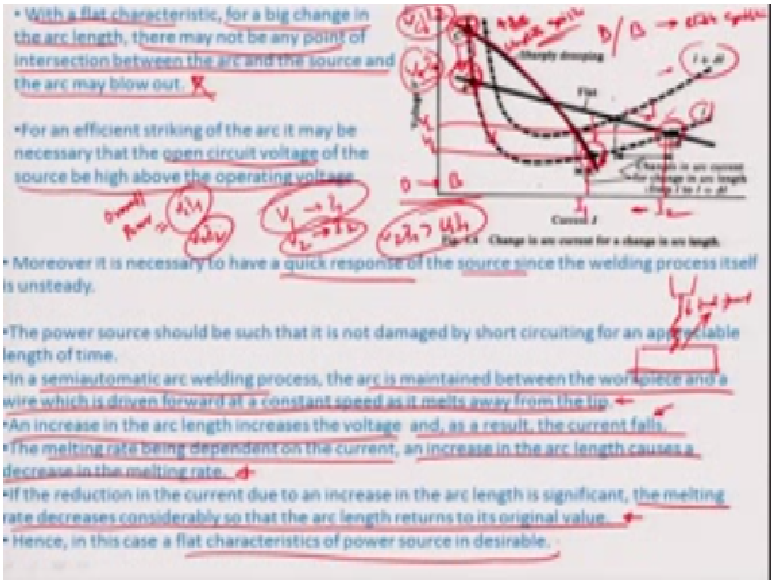

- With a flat characteristic, for a big change in the arc length, there may not be any point of intersection between the arc and the source and the arc may blow out.
- For an efficient striking of the arc it may be necessary that the open circuit voltage of the source be high above the operating voltage.
- Moreover it is necessary to have a quick response of the source since the welding process itself is unsteady.
- The power source should be such that it is not damaged by short circuiting for an appreciable length of time.
- In a semiautomatic arc welding process, the arc is maintained between the workpiece and a wire which is driven forward at a constant speed as it melts away from the tip.
- An increase in the arc length increases the voltage and, as a result, the current falls.
- The melting rate being dependent on the current, an increase in the arc length causes a decrease in the melting rate.
- If the reduction in the current due to an increase in the arc length is significant, the melting rate decreases considerably so that the arc length returns to its original value.
- Hence, in this case a flat characteristics of power source in desirable.

So the arc in the figure so typical arc characteristics for two different arc lengths in term are also indicated see the dashed lines here the intersection of the characteristics of this source and the arc determine the optimum point but I would like to just point out to a very important situation which is relevant to ability of system. Let us look at point B for example and the point B so there are actually points formulating were the intersection for the power source characteristics takes place with respect to the VI characteristics of the arc.

And let say we are moving to D to B oaky so therefore probably because the overall arc length is bulging and we continue the more voltage you can see whether current is rising oaky so if I consider the different volume here in this particular case I can find out this to be I_1 and I_2 and I can formulate this to be V_2 and V_1 so obviously you conceive that corresponding to V_1 there is an current I_1 and it voltage in high ways in V_2 the current diverges to I_2 okay.

So therefore the overall power would absolute the V_1 I_1 and segregates the V_2 I_2 and it is power of consumption the V2 I2 is the power of the consumption okay. so you can understand if there is an increase in the voltage the power source which running a constant power, power is equal to V_I okay let ensure that the current produces so that would comes back you know to the normal point of operation V.

Whether in this case if may not be the case somehow the characteristic intersecting ith the some power characteristics of C. let say example there is a point C here and from point C here we transmission to A for the voltage at Vc , current is I_C and voltage at A is V_A current is I_A. so as you can see here with the reduction in the voltage the current increases as still in the roadmap i.e. its all in the characteristics curve. so therefore this situation may easily be arrived as power source may the voltage current characteristics keeps on unstably going away until it reaches particular region.

So therefore we call the points D or B more or less stable equilibrium that whenever there is a increase in the voltage it ensures the power source ensures that the equilibrium points shifts back whereas in case of A and C it may be consider as non-stable equilibrium. So please understand this concept very well that A and C or normally you know would not be self-stabilizing or supposing there is an drooping down on the voltage it will not never come back to point C okay.

Because the VI current is basically the voltage current is going down there is downwards power overall power is consume for the sustaining the arc is lesser or lesser. but in this case the power rises obviously the arc will have to come back you know unless you wanted it of course blow off so if it prevent the arc from blow off obviously it has to come back to the point D from the point B so having said that the other issue I would like to see here.

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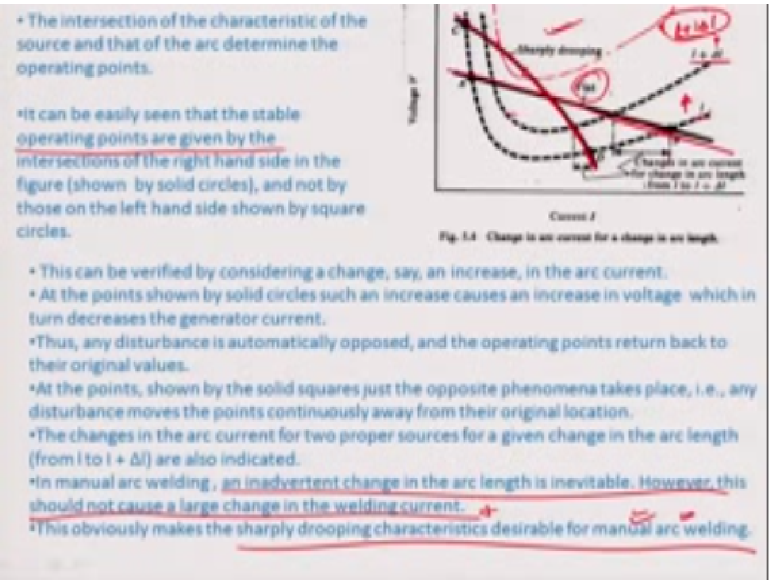

- The intersection of the characteristic of the source and that of the arc determine the operating points.
- It can be easily seen that the stable operating points are given by the intersections of the right hand side in the figure (shown by solid circles), and not by those on the left hand side shown by square circles.

Fig. 1.4 Change in arc current for a change in arc length

- This can be verified by considering a change, say, an increase, in the arc current.
- At the points shown by solid circles such an increase causes an increase in voltage which in turn decreases the generator current.
- Thus, any disturbance is automatically opposed, and the operating points return back to their original values.
- At the points, shown by the solid squares just the opposite phenomena takes place, i.e., any disturbance moves the points continuously away from their original location.
- The changes in the arc current for two proper sources for a given change in the arc length (from l to l + Δl) are also indicated.
- In manual arc welding , an inadvertent change in the arc length is inevitable. However, this should not cause a large change in the welding current.
- This obviously makes the sharply drooping characteristics desirable for manual arc welding.

If you are considering both the flat as well as the drooping characteristics as you can see probably here so this is the sharply drooping characteristics and this is the flat characteristics. These are two different power sources I can easily find out what power source should be appropriate for what operation. For example let say when we talk about manual welding and manual arc length. There is not very high level of control okay which is their on the drop Inter electrode gap because the electrode is going to move over the work piece upto a certain extend and because of that the manual arc welding itis always much sure what it is going to be operative length for the arc between the work piece and the electrode.

But if you look at the characteristics here supposing there is a change in the air column from L to L+ΔL already the characteristics are gone up if it is increasing twice ΔL, there is a possibility that the power source characteristics may actually not at all have an operating point on this flat curve right here okay. so if there is no control on the length particular by the operator, I think the drooping characteristics would be more feasible here.

Because of the sudden drooping nature or sudden change in the current because of changing in the voltage there still you know a scope of intersection for a greater amount of length change in comparison that of a straight line power. you can see that the you cannot really accommodate anymore increase in the length from L+ΔL. Let say L+2ΔL, but sharply drooping characteristics which still be able to draw some operating point you know.

If you keep on increasing this relationship in the arc. so what is important then, sharply drooping characteristics normally the way to go. We talked about manual welding process and you can say that if the flat characteristics for a big change in the arc length there may not be any interception between the arc and the source and the arc may be simply blown out and it may not be good feeding characteristics for a manual arc welding process . But for efficient striking of the arc it may also be the necessary that the open circuit voltage which is thee highest voltage probably here okay.

Where the current is more or less 0. the source should be high above the voltage of the arc okay. so more this voltage better it is. now when we talked about when the flat characteristics would serve the better purpose obviously it drooping characteristics would have very quick response you know in terms of VI variation because of the nature of the curve as you can see here. it is suddenly drooping down because of the large change in voltage corresponding to small change in current.

So the question of the flat characteristics coming out in picture when we talked about semi automatic arc welding process where the arc maintain between the work piece and the wire which is driven forward at the constants speed okay. so the idea is in a semi-automatic process there is a wire feed in the mechanisms which sends out the wire and there is a work piece which is there in the arc is stuck between those wires and the work piece.

And this normally is fed forward okay so the wire is fed forward the idea is at the wire is made by the filler material which melts away as strikes forward and as the welding happens length wise manner Let say the welding is going in this direction obviously the melting is going to be deposited okay. and so there is going to be the volume continuity for doing large weld of the length L. so increase in the air length, in this case there is increasing voltage oaky where you can see probably here.

So voltage is increases from let say you know L to L+ΔL and as a result the current should fall down the melting rate becomes dependent on the current. you want to melting rate as uniform as possible so increasing the arc length causes decrease in the melting rate. It is obviously the current would fall down because of increasing the voltage. So you can see that arc length changes from L+ΔL. let say L some value there is a rise in the voltage here and there is a fall in the current okay. so reduction of the current due to increases in arc length is significant as melting rate decreases.

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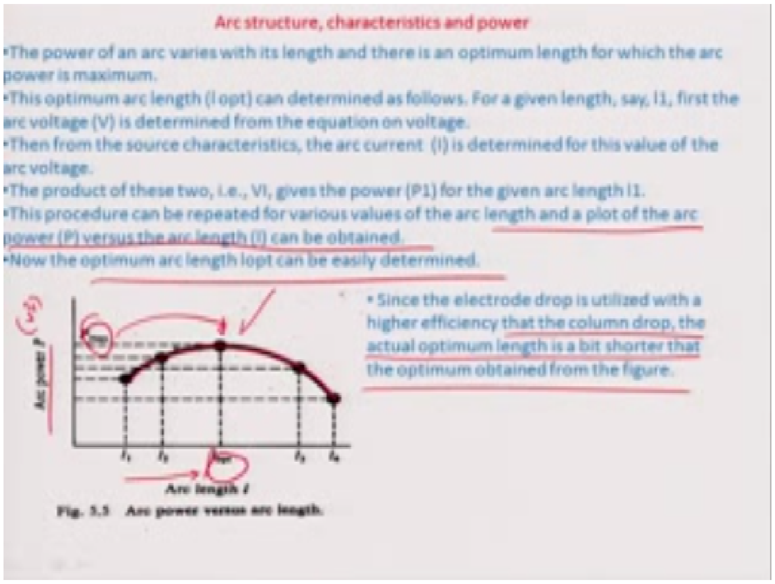

Arc structure, characteristics and power

- The power of an arc varies with its length and there is an optimum length for which the arc power is maximum.
- This optimum arc length (l opt) can determined as follows. For a given length, say, l1, first the arc voltage (V) is determined from the equation on voltage.
- Then from the source characteristics, the arc current (I) is determined for this value of the arc voltage.
- The product of these two, i.e., VI, gives the power (P1) for the given arc length l1.
- This procedure can be repeated for various values of the arc length and a plot of the arc power (P) versus the arc length (l) can be obtained.
- Now the optimum arc length lopt can be easily determined.

- Since the electrode drop is utilized with a higher efficiency that the column drop, the actual optimum length is a bit shorter that the optimum obtained from the figure.

Fig. 5.5 Arc power versus arc length.

So the arc length is returns to its original value. So hence in the flat characteristics of the power source will be more desirable. so that's how you associate the flat characteristics with respect to the drooping down characteristics and having said that now the important issue is that what is the optimum power at which arc should be operated or at the optimum length for example at which the optimum arc can do the power transfer so it plot the arc V-I of the you know the curve I had shown earlier with respect to the various lengths of the arc. this is how it happens the curve comes like the way and inverted curve like this then there is optimum power which is always operate and there is an optimum length corresponding to this optimum power at which should always operate.

And maximum power used effectively and dissipated in a least manner. so this procedure can be repeated for the various values of arc lengths and it plotted of the arc power versus arc length can be obtain because optimum arc length will optimum can be easily determine since the electrode drop is utilize the higher efficiency than the column drop the actual optimum length is a bit shorter than the optimum length obtained in the figure and this kind of optimization let us look up a example how we like to optimize the arc power.

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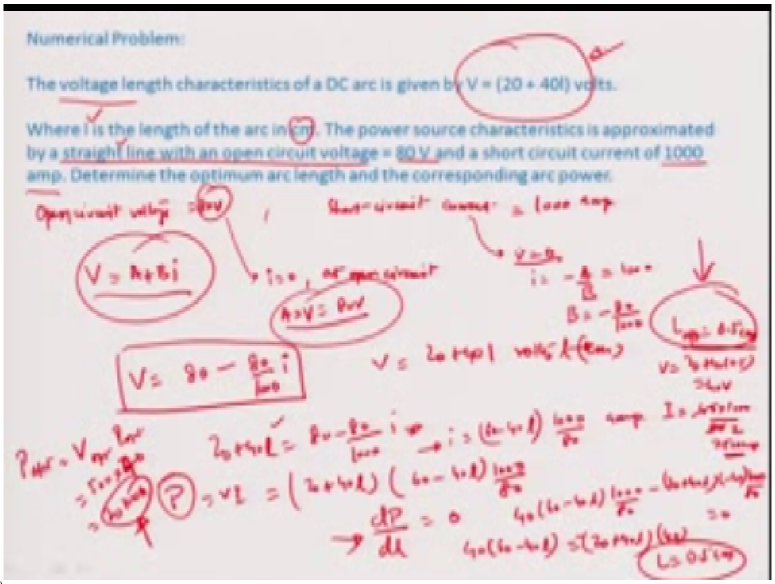

Numerical Problem:

The voltage length characteristics of a DC arc is given by V = (20 + 40l) volts.

Where l is the length of the arc in cm. The power source characteristics is approximated by a straight line with an open circuit voltage = 80 V and a short circuit current of 1000 amp. Determine the optimum arc length and the corresponding arc power.

$$V = \left(80 - \frac{80}{1000} I\right) volts$$

$$V = (20 + 40l)\, volts$$

$$\Longrightarrow 80 - \frac{80}{1000} I = 20 + 40l$$

$$\Longrightarrow I = (60 - 40l)\frac{1000}{80} Amp$$

$$\Longrightarrow P = VI = (20 + 40l) * (60 - 40l)\frac{1000}{80} volt - amp.$$

$$\Longrightarrow \frac{dP}{dl} = 0$$

$$\Longrightarrow 40(60 - 40l) - 40(20 + 40l) = 0$$

$$\Longrightarrow 1600 = 3200l$$

$$\Longrightarrow l = 0.5\, cm$$

$$\Longrightarrow P_{max} = (20 + 40 * 0.5) * (60 - 40 * 0.5)\frac{1000}{80} volt - amp = 20\, kVA$$

So in this particular example we have given a voltage length characteristics has 20+40 volts and L is a length of an arc is cm which is to be recorded the power source characteristics approximate by a straight line when the open circuit voltage 80V **and** the short circuit current of 1000 amperes so it determines the optimum arc length and corresponding arc power. so let us first of all analytically write down the V-I relationship. so as been recorded here that there are two statements that is been open circuit voltage corresponds to about 80V and short circuit current corresponds to about 1000 A and so let us so as the V-I relationship is linear in this particular case we can write V to be equal to A+ BI where A and B are constants.

This is like a straight line equation between V and I so linear characteristics . so having said that in if I wanted to apply the first boundary condition here which corresponds to the open circuit voltage so obviously I0 at open circuit and so if we put I0 value here A becomes equal to V and V is 80 v. so therefore A comes 84 . similarly if I can solve this for the short circuit current so add to the short circuit basically voltage 0 because it is like a short circuited situation the it is a true current through pass no resistance.

So therefore I becomes = - A / B okay and A has already been found to be 80 v earlier and I the short circuit current is about 1000 amp meaning there by the B becomes – 80/ 1000 okay. so that is how we can recorded B so V now can be written down as 80 – 80/ 1000i and this is the linear voltage characteristics from the boundary condition that has been mentioned we also know that v is written as 20 + 40 *l* volts where *l* is in cm. it has been given in the question itself so obviously then 20+40 l becomes = 80 – 80/ 1000i.

And I can be found out in this particular case as 40l with the minus sign + 60 / 80 * 1000amp. so that is how you can make I happen so you know that the power P is written as VI so in this case everything is determined in terms of L so already we have voltage to be written as 20 + 40 L and and the current written as 60 – 40 L times of 1000/ 80 .so that is how the power is determined and this case if we apply the maximum power condition corresponding to the length *l*.

The first derivative of p with respective L should be = 0 sew do that here we have 40 times of so 40 times of 60 – 40 L 1000/ 80 – (20+ 40 L) times of – 40 / 1000 * 1000/ 80 should be = 0. in other words we can say 40 times of 60 – 40 L = 20 + 40- L times of 40 with the – sign or that gives us the value of L = 0 .5 cm okay. so the optimum length than in this case L_{opt} is found out to be 0.5 cm and the corresponding arc power can be now be determined so V becomes = 20+ 40 times of 0. 5 is about 40 volts similarly the current *I* can be rerecorded as the relationship that you have between current and length here.

$$\Longrightarrow \frac{dP}{dl} = 0$$
$$\Longrightarrow 40(60-40l) - 40(20+40l) = 0$$
$$\Longrightarrow 1600 = 3200l$$
$$\Longrightarrow l = 0.5\,cm$$

So *I* becomes = 40 times of 1000 / 80 this is about 500 amps and the total optimum power that comes into here is the V_{opt} I_{opt} which is actually equal to 500 times of 40 v which is nothing but about 20 kVa. so this is how the optimum power will be and this is optimum length of the source would be. so I would like to just illustrate here that whenever such design problems come through you should be able to engage by first converting the current into length terms and then multiplying with the voltage already present in length term.

$$\Longrightarrow P_{max} = (20 + 40 * 0.5) * (60 - 40 * 0.5)\frac{1000}{80} volt - amp = 20\, kVA$$

So that you can have a power and the optimize the power with respect to the length to find out what is the operating point and from the operating point you can always get the operating power okay at which you should actually operate and this is the operating power which is drawn in order to ensure that earlier dissipation happen and all the power is more or less a absorbed power and there is hardly any reflected power from the system.

So with that I think I would like to just sort of you know round of the arc design problem there are many other sources of heat which are utilized from time to time for again you know doing the.

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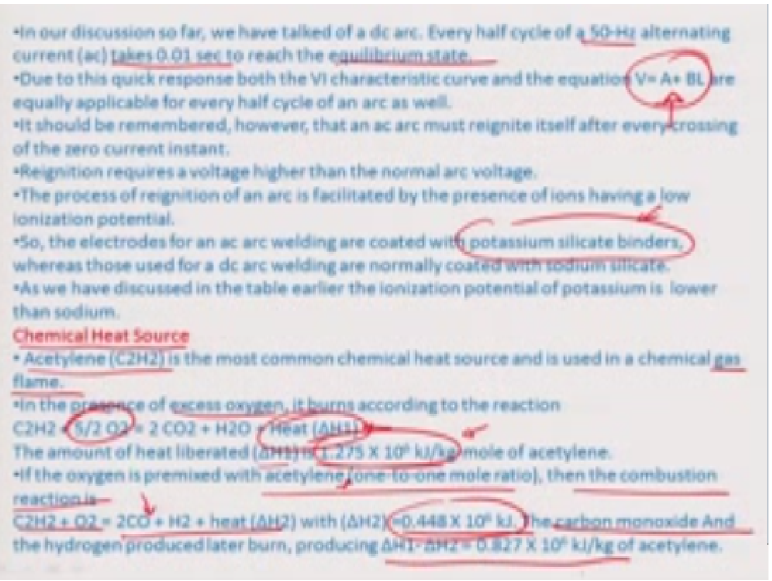

- In our discussion so far, we have talked of a dc arc. Every half cycle of a 50-Hz alternating current (ac) takes 0.01 sec to reach the equilibrium state.
- Due to this quick response both the VI characteristic curve and the equation V= A+ BL are equally applicable for every half cycle of an arc as well.
- It should be remembered, however, that an ac arc must reignite itself after every crossing of the zero current instant.
- Reignition requires a voltage higher than the normal arc voltage.
- The process of reignition of an arc is facilitated by the presence of ions having a low ionization potential.
- So, the electrodes for an ac arc welding are coated with potassium silicate binders, whereas those used for a dc arc welding are normally coated with sodium silicate.
- As we have discussed in the table earlier the ionization potential of potassium is lower than sodium.

Chemical Heat Source

- Acetylene (C2H2) is the most common chemical heat source and is used in a chemical gas flame.
- In the presence of excess oxygen, it burns according to the reaction

C2H2 + 5/2 O2 = 2 CO2 + H2O + Heat (ΔH1)

The amount of heat liberated (ΔH1) is 1.275 X 10^6 kJ/kg mole of acetylene.

- If the oxygen is premixed with acetylene (one-to-one mole ratio), then the combustion reaction is

C2H2 + O2 = 2CO + H2 + heat (ΔH2) with (ΔH2) =0.448 X 10^6 kJ. The carbon monoxide And the hydrogen produced later burn, producing ΔH1- ΔH2 = 0.827 X 10^6 kJ/kg of acetylene.

Melting of the material in the welding process. so in our discuss so far so in our discussion so far we have mostly talked about DC arc but there is a also an existence of something called an AC arc where there is an alternating current of 50 Hz frequency and basically it takes about 0.01 s to reach the equilibrium state. so this a sort of quick response system and although the equation is actually determined by the same manner.

A+ BL equally applicable but it is true for every half cycle because the polarity would change after every half cycle and then the arc may as well need to get reignited for every half cycle. so therefore it is important for the designer to ensure that the coating that is there on the electrodes are of materials which is a lower ionization potential so in this AC arc welding case most the coating is you know potassium silicate binders makes sort of a very good stable AC arc.

But in the coating is tend to DC arc then something like sodium silicate also would result in you know stable arc or sticking an arc because we do not need really a low ionization potential in this case. AC arc however the reignition factor comes into picture, so therefore always the arc becomes stable if the ions which are present are easily ignitable that easily you know they can easily ionize and they have a overall lower ionization potential.

In fact potassium silicate binders when they evaporate they do produce very easily ionizable constituents which should be in gaseous atmosphere where there is this election the secondary electron which would get produced okay. the free electron which should get produced because the presence of such binders. There are many other sources as I had discussed like the chemical heat source where you can use as acetylene and oxygen to produce gas flame so acetylene and oxygen burns out you know in different conditions.

So in the presence of excess oxygen for example it burns according to this reaction right here C2H2+ 5/2 O2 = 2 CO2+ H20 + heat ΔH1. this is highly exothermic process again. the amount of heat liberated ΔH1 is about 1.275 times 10 ^{6} kg/ kJ-mole of acetylene. If the oxygen is premixed with acetylene in 1 to 1 mole ratio then the combustion reaction comes equal to C2H2 + O2 is 2 CO + H2. so you can see that it is a starved of the oxygen. here it goes abundance of the oxygen supply. so one kind of premixed cases, the H_2 that is liberated here is comparatively lower in you know as in case of excess oxygen.

And the carbon monoxide and hydrogen produced later burn out again at a second step or additional step to produce about 8.27 x 10^6 kJ/kg of acetylene.

$$C_2H_2 + 2.5O_2 = 2CO_2 + H_2O + heat\left(\Delta H_1\right)$$

$$C_2H_2 + O_2 = 2CO + H_2 + heat\left(\Delta H_2\right)$$

$$\left(\Delta H_1\right) - \left(\Delta H_2\right) = 0.827 * 10^6 \frac{kJ}{kg} - mole$$

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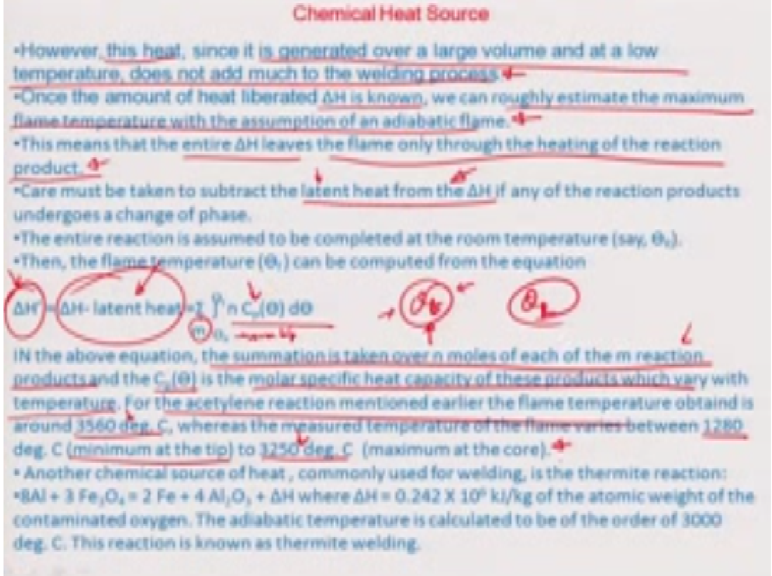

Chemical Heat Source

- However, this heat, since it is generated over a large volume and at a low temperature, does not add much to the welding process.
- Once the amount of heat liberated ΔH is known, we can roughly estimate the maximum flame temperature with the assumption of an adiabatic flame.
- This means that the entire ΔH leaves the flame only through the heating of the reaction product.
- Care must be taken to subtract the latent heat from the ΔH if any of the reaction products undergoes a change of phase.
- The entire reaction is assumed to be completed at the room temperature (say, θ_0).
- Then, the flame temperature (θ_f) can be computed from the equation

$$\Delta H' = \Delta H - \text{latent heat} = \sum_m \int_{\theta_0}^{\theta_f} n\, C_p(\theta)\, d\theta \qquad \theta_f \qquad \theta_0$$

IN the above equation, the summation is taken over n moles of each of the m reaction products and the $C_p(\theta)$ is the molar specific heat capacity of these products which vary with temperature. For the acetylene reaction mentioned earlier the flame temperature obtaind is around 3560 deg. C, whereas the measured temperature of the flame varies between 1280 deg. C (minimum at the tip) to 3250 deg. C (maximum at the core).

- Another chemical source of heat , commonly used for welding, is the thermite reaction:
- $8Al + 3\,Fe_3O_4 = 2\,Fe + 4\,Al_2O_3 + \Delta H$ where $\Delta H = 0.242 \times 10^6$ kJ/kg of the atomic weight of the contaminated oxygen. The adiabatic temperature is calculated to be of the order of 3000 deg. C. This reaction is known as thermite welding.

So this heat however is generated over a large volume and at a low temperature does not add much to the welling process once the amount of heat liberated ΔH is known. you can roughly estimate the maximum flame temperature with the assumption of an adiabatic flame with an assumption of an adiabatic flame which means really that the entire enthalpy change which happens is because of whatever heat transfer takes place out of the flame through only the heating of the reaction products okay.

And nothing else actually so care must be taken to subtract the latent heat if supposing there is a phase change associated with some you know property or some of the gas may be and therefore may be there is some water vapor or something which is present and then there is some kind of an absorption from this particular enthalpy change in terms of heat of latent heat so that has to be taken out of this ΔH.

$$\Delta' H = \Delta H - latent\, heat = \sum_{m} \int_{\theta_R}^{\theta_f} n C_p(\theta)\, d\theta$$

So supposing ΔH is the total amount heat which is transferred adiabatically through the flame because of the heating of the reaction products. and latent heat is let us say take off from ΔL so that is actually the total amount of enthalpy change produced and it can be put together as integral of n Cp θ dθ, θ baring between θ r to θt, θ r is the room temperature and you can assume that the summation is taken over n moles of the each of the m reactions reaction products which represent. and θp or Cp θ is basically the molar specific heat capacity of these products.

Which vary with the temperature okay so from this you can really calculate the room temperature θt once the so the flame temperature θ t was the room temperature etc and other values like Cp θ etc are plugged into this equation. ΔH’ is basically the total amount of heat generated by the reaction products, so typically for the acetylene reaction mentioned earlier.

The flame temperatures which obtained around 3560^0 C which is good enough for melting of metals particularly iron based metals. where as the measured temperature of the flame vary between 1280^0 minimum at the tip of the flame to 3250^0 maximum at the core of the flame. so another chemical source which are normally used or for you know in this case is probably thermites which are any transition metal size like iron oxide, copper oxide so on so forth and aluminum and these are also again very effective in generating heat to an extent.

Where the adiabatic you know temperatures is calculated to be about close to 3000^0C in such sources. so therefore we studied about acetylene source we also studied about this thermites reaction based source.

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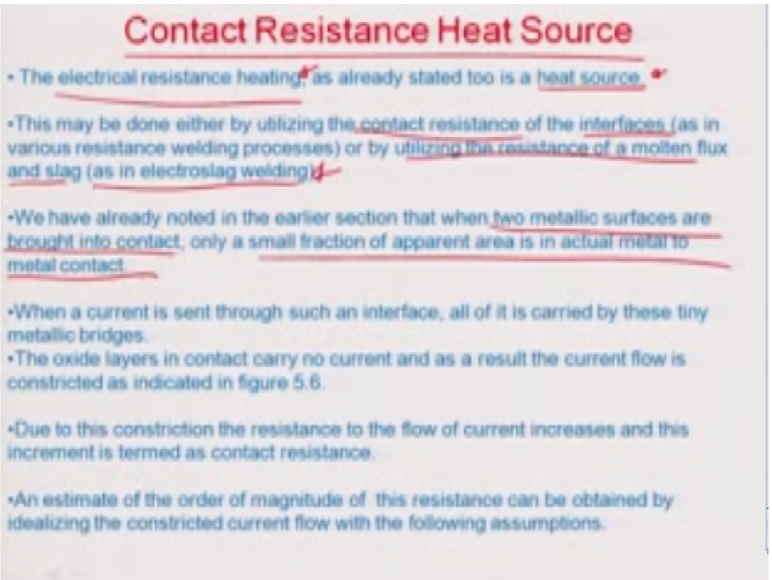

Contact Resistance Heat Source

- The electrical resistance heating, as already stated too is a heat source.
- This may be done either by utilizing the contact resistance of the interfaces (as in various resistance welding processes) or by utilizing the resistance of a molten flux and slag (as in electroslag welding).
- We have already noted in the earlier section that when two metallic surfaces are brought into contact, only a small fraction of apparent area is in actual metal to metal contact.
- When a current is sent through such an interface, all of it is carried by these tiny metallic bridges.
- The oxide layers in contact carry no current and as a result the current flow is constricted as indicated in figure 5.6.
- Due to this constriction the resistance to the flow of current increases and this increment is termed as contact resistance.
- An estimate of the order of magnitude of this resistance can be obtained by idealizing the constricted current flow with the following assumptions.

So now we will try to look at another aspect of a you know the heat source which is basically the contact resistance heat source which happens in most of the industrial application related to automotive etc the spot holding is a very important phenomena .so as we know that the electrical resistance heating is also responsible for doing joining it can also be used as local heat source and intensely high temperature heat source.

And this may be done either by utilizing contact resistance of the interfaces okay as a in various resistance welding process or by utilizing the resistance of molten flux and slag as in the electoslag welding process, so both are contact resistance based heating and we have already noted in the earlier section that when two metallic surfaces are brought into contacts so small fraction of the apparent area. The actually metal to metal contact so supposing there are these tiny metallic bridges.

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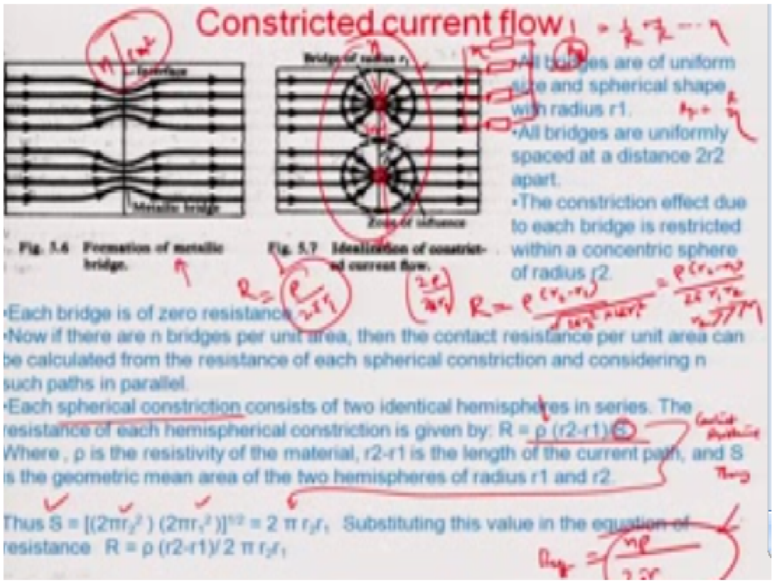

Constricted current flow

Fig. 5.6 Formation of metallic bridge.

Fig. 5.7 Idealisation of constricted current flow.

- All bridges are of uniform size and spherical shape with radius r1.
- All bridges are uniformly spaced at a distance 2r2 apart.
- The constriction effect due to each bridge is restricted within a concentric sphere of radius r2.
- Each bridge is of zero resistance
- Now if there are n bridges per unit area, then the contact resistance per unit area can be calculated from the resistance of each spherical constriction and considering n such paths in parallel.
- Each spherical constriction consists of two identical hemispheres in series. The resistance of each hemispherical constriction is given by: R = ρ (r2-r1)/S

Where , ρ is the resistivity of the material, r2-r1 is the length of the current path, and S is the geometric mean area of the two hemispheres of radius r1 and r2.

Thus $S = [(2\pi r_2^2)(2\pi r_1^2)]^{1/2} = 2\pi r_2 r_1$ Substituting this value in the equation of resistance $R = \rho(r2-r1)/2\pi r_2 r_1$

$$R=\frac{\rho\left(r_2-r_1\right)}{S}$$

$$\Longrightarrow S=\sqrt{\left(2\pi r_2^2\right)\left(2\pi r_1^2\right)}=2\pi r_2 r_1$$

$$\Longrightarrow R=\frac{\rho\left(r_2-r_1\right)}{2\pi r_2 r_1}\approx\frac{\rho}{2\pi r_1}$$

$$\Longrightarrow R_c=\frac{2}{n}\frac{\rho}{2\pi r_1}=\frac{\rho}{n\pi r_1}$$

$$\Longrightarrow R_c=\frac{0.85*\rho}{n\pi r_1}$$

Which would happen between two such materials you know you can see these bridges getting formulated here because of whatever deformation etc, and so if I assume the radios of such a bridge to r_1. so this is r_1 and we also assume that between the two bridge is a gab of about 2r2 okay so we can easily calculate the contact resistance and this A comes from the electrical engineering theory of contact resistance between surfaces which are not going to go into but for.

Such spherical constrictions let us say there n such constrictions per selling this square you have a resistance ½ resistance done by this you know half bridge which actually connects between both potential points across the two different members is given by ρ(r2 – r1) / s where s is the geometric mean between the two times the circular area $\pi r2^2$ and $\pi r1^2$ .so I do not want to really get into the group of this because this is actually available from contact theory okay.

Or contact resistance theory and just in the interest of time I would go ahead and apply these in order to calculate some of the resistances and some of the heating refracts which lead to a temperature rise in the situation. so the resistance between now these two plates with n parallel bridges across each other would be actually each bridge would have a resistance of ρ(r2 – r1)/ √ 2 π r2^2 times of 2 π r1^2 which actually becomes ρ times r2- r1/ 2 π taken common r1 r2.

$$\Longrightarrow S=\sqrt{\left(2\pi r_2^{\,2}\right)\left(2\pi r_1^{\,2}\right)}=2\pi r_2 r_1$$

$$\Longrightarrow R=\frac{\rho\left(r_2-r_1\right)}{2\pi r_2 r_1}\approx\frac{\rho}{2\pi r_1}$$

If I assume that r2 the resistance between the bridges out of the area of the pressures is much larger in compression to r1 then this resistance between of each bridge comes out to be = ρ /2 π r1 and we can assume that half bridge contributes this so therefore both the half bridges here and near are in series, so the total resistance should be 2 ρ / 2 π r1 and there are n such bridges per unit area.

$$\Longrightarrow R_c=\frac{2}{n}\frac{\rho}{2\pi r_1}=\frac{\rho}{n\pi r_1}$$

In siding those square so these are n bridges or more or less parallel resistance you can assume them to be you know electrically distributed like parallel resistances okay. and so you can convert this whole expression here as 1/r+ 1/r + 1 up to n is the total effective resistance of the bridge which becomes equal to r effectives becomes equal to r/ n okay so in this particular case I would have the r effective of these over all resistance between the n bridges per cm^2 as n ρ / 2 π r1 so typically this is how the contact resistance between the hits are calculated.

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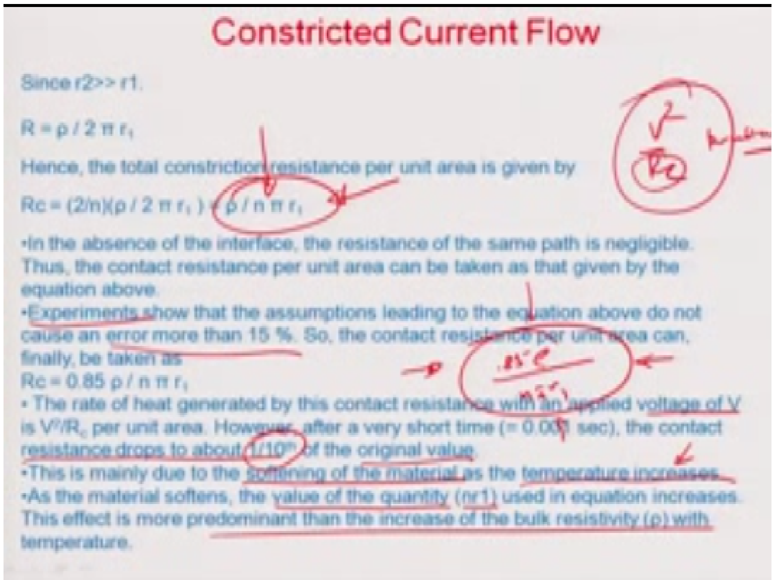

Constricted Current Flow

Since r2>> r1.

$R = \rho / 2 \pi r_1$

Hence, the total constriction resistance per unit area is given by

$Rc = (2/n)(\rho / 2 \pi r_1) = \rho / n \pi r_1$

- In the absence of the interface, the resistance of the same path is negligible. Thus, the contact resistance per unit area can be taken as that given by the equation above.
- Experiments show that the assumptions leading to the equation above do not cause an error more than 15 %. So, the contact resistance per unit area can, finally, be taken as
$Rc = 0.85 \rho / n \pi r_1$
- The rate of heat generated by this contact resistance with an applied voltage of V is V^2/R_c per unit area. However, after a very short time (= 0.001 sec), the contact resistance drops to about 1/10th of the original value.
- This is mainly due to the softening of the material as the temperature increases.
- As the material softens, the value of the quantity (nr1) used in equation increases. This effect is more predominant than the increase of the bulk resistivity (ρ) with temperature.

And being illustrate in this formula right here ρn π r1 and if you look at the experimental values really the error rate is not more than about 15% so that is why we actually take little lower value of the resistance as 0.85 and π r1 where this 0.5 is really an experimental error you can say and we know it is not like I mean it is not incomplete agreement with the theoretical approach to contact resistance so it is already infinite percent of this theoretical predicted radiance which happens.

$$\Longrightarrow R_c = \frac{0.85 * \rho}{n\pi r_1}$$

So the rate of heat generated by this contact resistance with an applied voltage of V is basically square of V/Rc and that is the resistance you know just because the resistance is that permit area therefore this you would also be per unit area and after a very short time the contact resistance kind of drops to about 1/ 10 of the original value of the resistance is due to the softening of the material and may be you know the plastic deformation of each and every individual bridges.

And as the temperature increases also there is a change in the resistance to be of a material so as a material soft since the value of the quantity r1 use the equation increases and this effect is predominant and things of the bulk resistivity ρ with the temperature.

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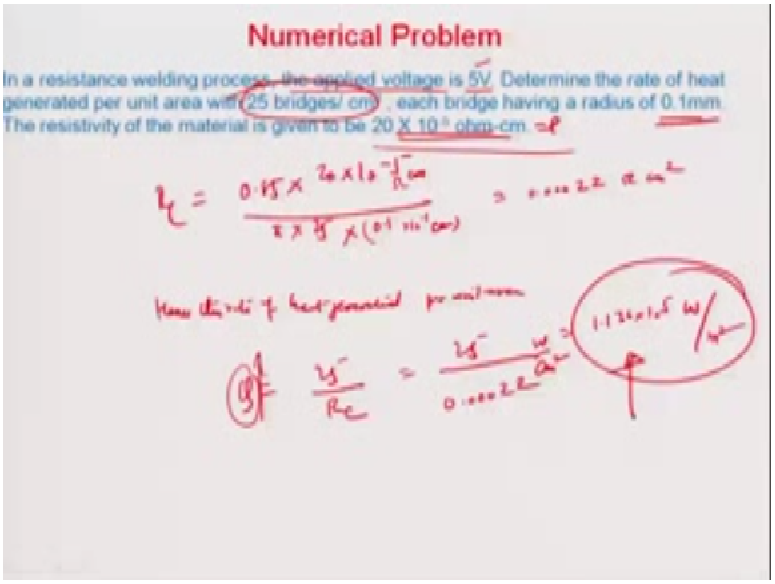

Numerical Problem

In a resistance welding process, ~~the applied~~ voltage is 5V. Determine the rate of heat generated per unit area with 25 bridges/ cm², each bridge having a radius of 0.1mm. The resistivity of the material is given to be 20×10^{-6} ohm-cm $= \rho$

$$R_c = \frac{0.85 \times 20 \times 10^{-6}\ \Omega\,cm}{\pi \times 25 \times (0.1 \times 10^{-1}\,cm)} = 0.00022\ \Omega\,cm^2$$

[illegible] of heat generated per unit area

$$q = \frac{5^2}{R_c} = \frac{25}{0.00022}\ \frac{W}{cm^2} = 1.136 \times 10^5\ W/cm^2$$

So let us actually solve a numerical problem so in a resistance welding process the applied voltages 5V and you have to determine the rate of heat generated per unit area with about n = 25 bridges/ cm$^{2.}$, so each bridge having a radios of 0.1mm so the resistivity of the material is about

20 10^{-5} ohm – cm. we need to first establish what is the contact to the resistance rc which is given by 85% of the ρ value that is 20* 10^{-5} ohm – cm even right here of the material divided by π times of n which is in this case 25 bridges / cm^2 times of r1 and r1 in this case is the bridge radios which is about 0.1.

So 0.1 times of 10^{-1} ρ everything is in cm this is ohms – cm so this should also be recorded in cm okay. so this becomes equal to about 0.00022 ohms cm^2 and the rate of heat generated per unit area would actually be given by the voltage which is about 5 volts about v^2/ rc and rc is already taken as 0.00022 so this becomes = 1.136* 10^5 W / m^2 so that is how the power density would be per unit area of the work surface. so that is how you can do these contact resistance problems when we talk about bridge resistance between two different sheets. so in fact as a summary in this particular lecture we try to look at very closely the arc characteristics talk about DC and AC arc. various other chemical beam source like as acetylene and oxygen mixed together, thermite reactions.

And then also established sort of working relationship between the contact resistance between two sheets which would be responsible for providing this value of heat Q which would raise the temperature of the sheets between and in-between and that would actually lead to local melting and welding because of again recrystallization and formula of solid phase between the two sheets. so having said that I come to the end of this particular module but in the next module we will learn a little more about how the metal gets transferred once.

For example all this and is it really dependent on electrical fields which are set up or been the magnetic fields which are set and how you can utilize that meal transfer process you advantage where you can actually do welding in different orientation including over head welding or for example top down welding so on so forth. we will probably also like into a few aspects of other mechanisms of joining for example at region base joining and solid liquid welding like brazing and soldering in the next lecture till and until then thank you so much for listening bye.

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