Advanced Manufacturing Processes
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Module - 5
Other Advanced Processes
Lecture - 4
Microwaves Processing of Materials

Welcome to this session on microwave processing of materials under the course advanced manufacturing processes. In the last two sessions we have discussed, learnt about the rapid prototyping processes, their different different technologies involved in rapid prototyping processes, rapid manufacturing, its advantages and applications. Some new trends in rapid prototyping technology limitations of the processes and future prospects were also discussed in those lectures.

Moving ahead, let us see another process completely different from the ones we have studied so far. This new field is microwave processing of materials. The microwave processing of materials is an emerging area, and has a bright prospects in manufacturing in the future. We have seen earlier in the advanced wielding section, which was discussed in module 4 the importance and benefits of green manufacturing processes. This microwave material processing is considered to be as one of the green manufacturing processes.

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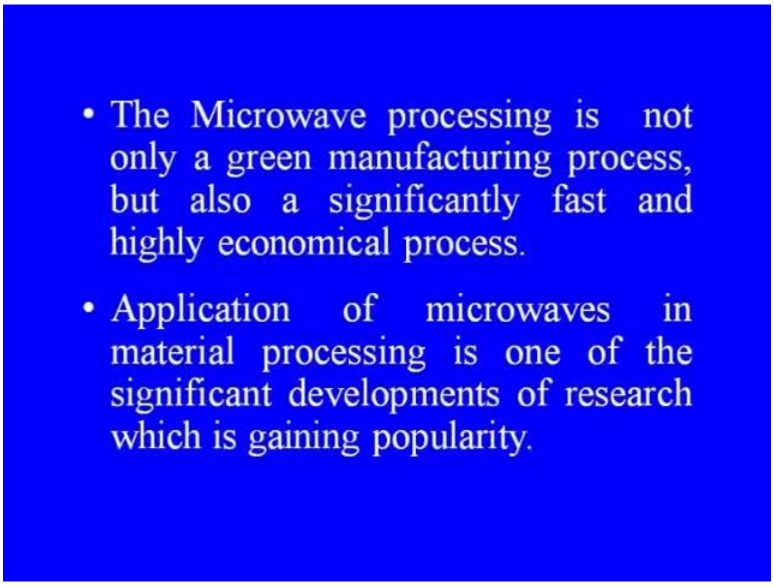

There are numerous advantages and environmental benefits through its usage. The microwave processing is not only a green manufacturing process, but also a significantly fast and highly economical process. Application of microwaves in material processing is one of the significant developments of research, which is gaining very fast popularity.

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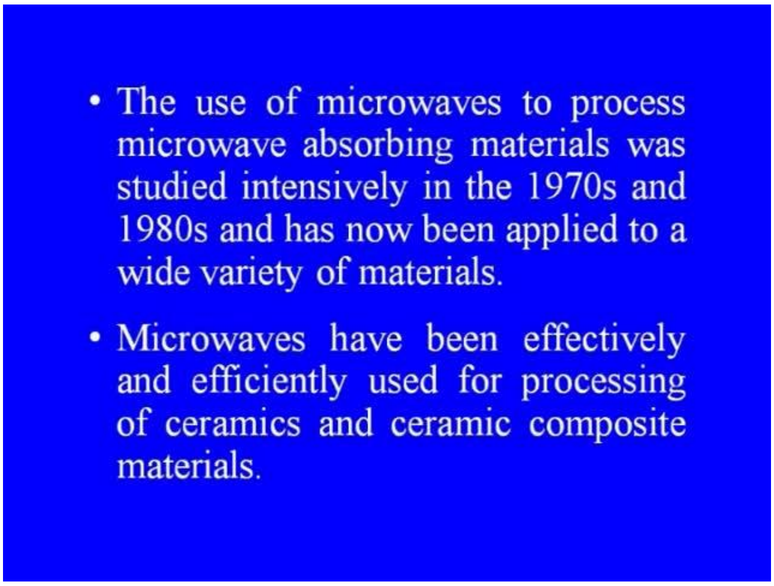

The use of microwaves to process microwave absorbing materials was studied intensive intensively way back in the year 1970s and 1980s and has now been applied to a wide variety of materials. Microwaves have been effectively and efficiently used for processing of ceramics and ceramic composite materials, then processing of rubbers especially rubber vulcanization and food materials.

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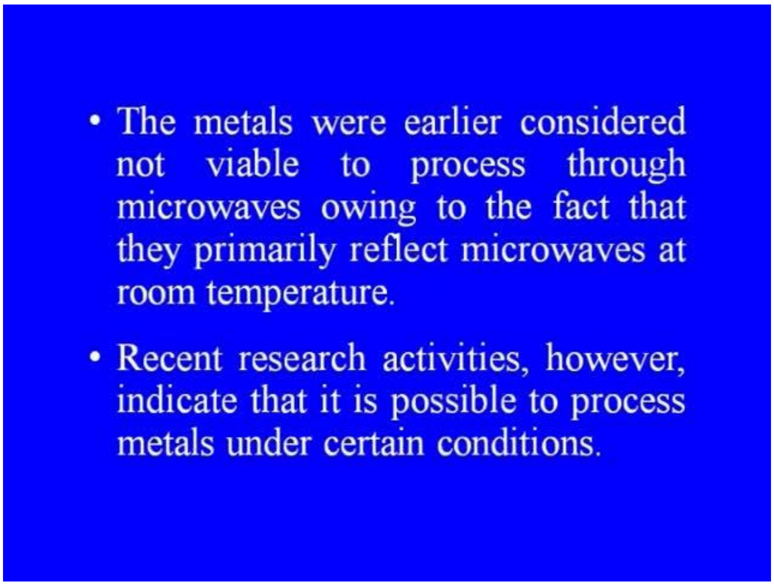

Metals were earlier considered not viable the process through microwaves going to the fact that they primarily reflect microwaves at room temperature. However, recent research activities indicate that there is possible to process metals under certain conditions. These all, these aspects we will discuss later on.

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The most recent application of microwaves has been in the field of metallic materials for sintering brazing joining melting and drilling of holes. The microwave processing of materials is a relatively new technology and provides a new approach to improve the physical properties of materials.

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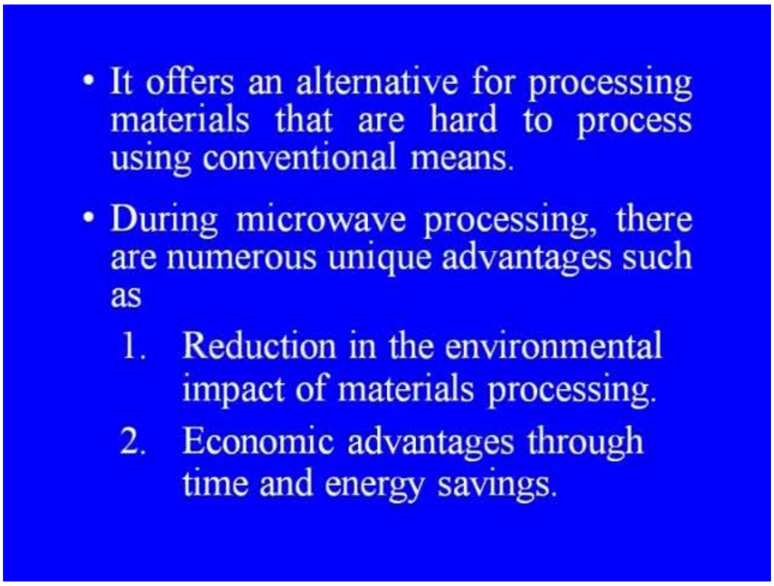

It offers an alternative for processing materials that are hard to process using conventional means. During microwave processing, there are numerous unique advantages such as reduction in the environmental impact of materials processing. Number two, economic advantages through time and energy savings, I will discuss all this in details later on.

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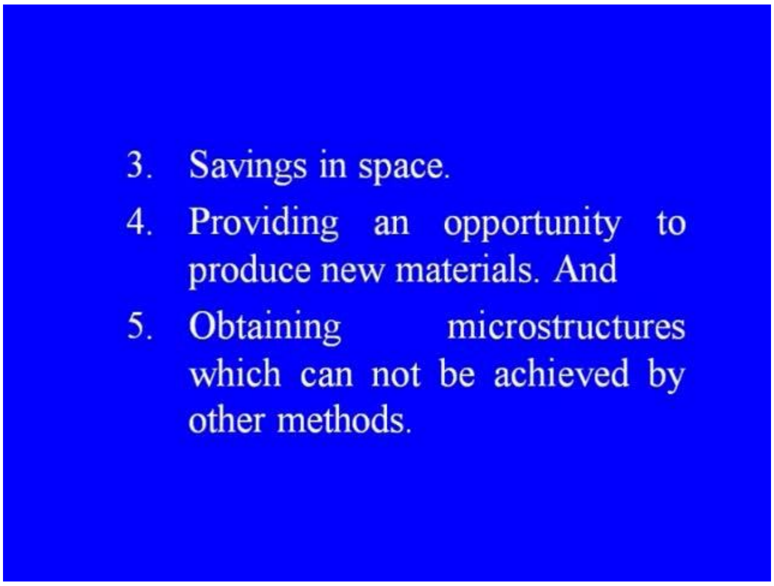

Savings in space, providing an opportunity to produce new materials, and obtaining microstructures which cannot be achieved by other methods.

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Microwave processing of materials was conceived over 50 years ago, but it was primarily developed for communications, some areas of processing such as cooking food, tempering and thawing and curing of wood and rubber products.

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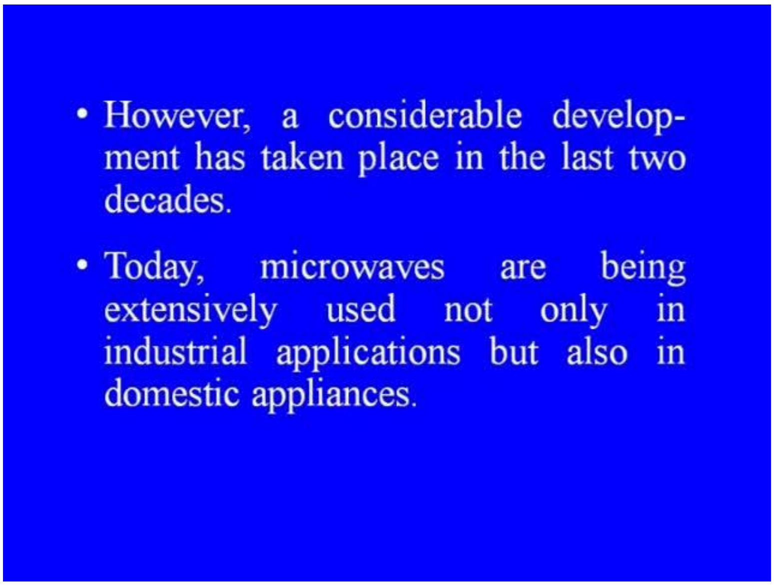

However, a considerable development has taken place in the last two decades. Today microwaves are being extensively used not only in industrial applications, but also in domestic appliances in the microwave processing.

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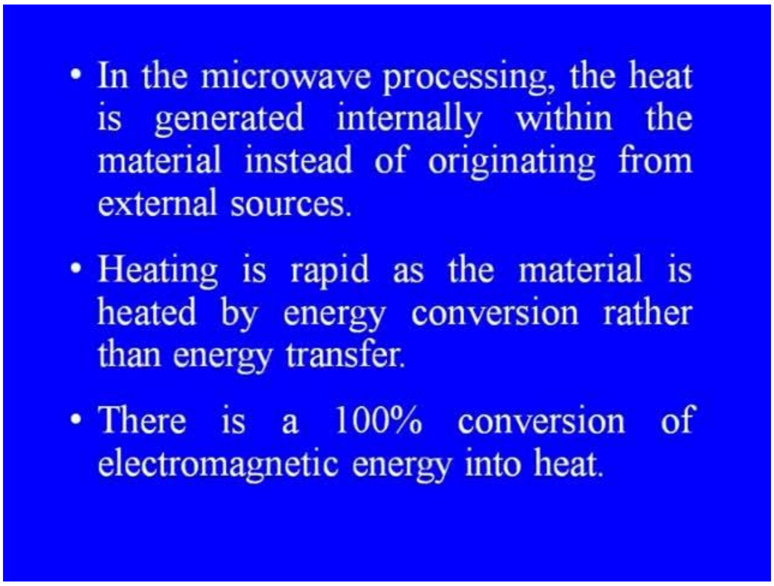

The heat is generated internally within the material instead of originating from external sources. This is a very basic difference between the conventional heating and microwave processing.

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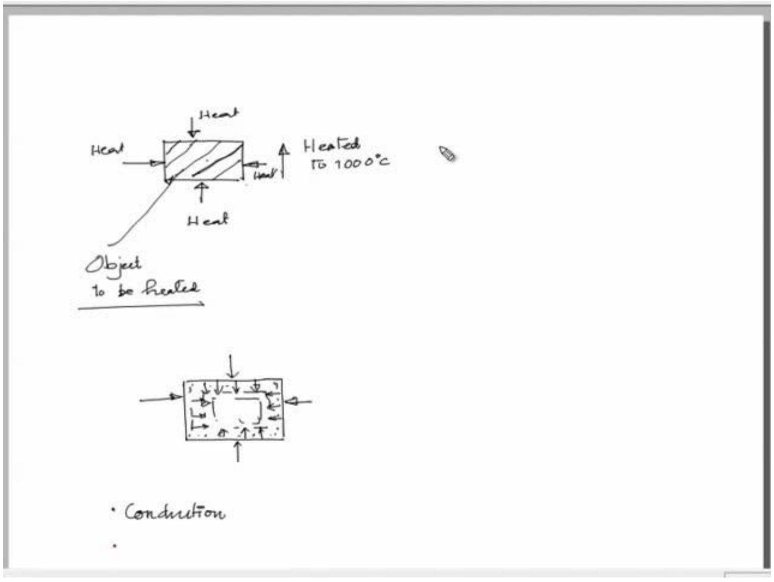

So, this can be explained like this. In conventional processing, say I have and object to be processed. The meaning of processing we are taking here as to be heated, like it is to be heated to a particular temperature. Say, heated to 1000 degree Celsius. Now, I have to apply heat in conventional methods either from one side or from all those side. So, this is the conventional means of applying heat. So, this can be from all the sides or can be from only one side, depending on the condition of the object. So, this is the object to be heated, object to be heated.

Say for example, very common example is, we heat the material for heat treatment. So, the heat treatment is a is a functional requirement or a process different processes are there for heat treatment to induce certain properties, which we probably cannot have in the material itself as it is. But through heat treatment we can induce some say for example, some hardness etcetera and that to hardness up to a deft and so on.

Now, in this case heat, so if we heat from all the sides, then heat transfer will take place. Say convention, by conventional means and this area will be heated up first, this layers will be heated first. Then it, next layer will be heated up, then next year will be heated up and so on. That means heat will move, heat waves will move in this direction or we can say energy supplied from outside will move, will be transferred from the outer layer to the inner in the conventional process of conduction.

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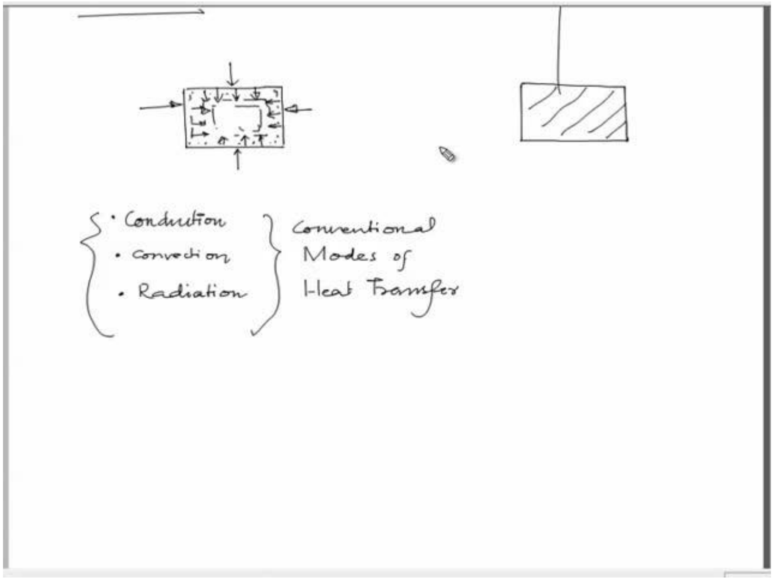

Say conduction or if the case be it may be convection convection or in some cases radiation If of course, it is a solid material then radiation will not come into picture. But these are the three conventional conventional modes of conventional modes of heat transfer. However, if we want to heat the same object with the application of microwave, then the situation is slightly different. Suppose, this is the object, the first condition has to be this material or this object should absorb microwave.

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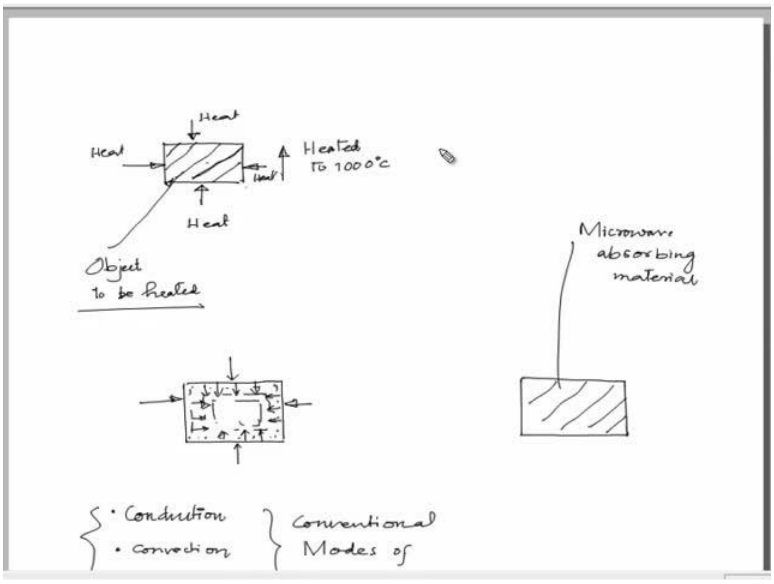

It should be microwave absorbing material, absorbing material. There are three kinds of materials as we will we will discuss later on.

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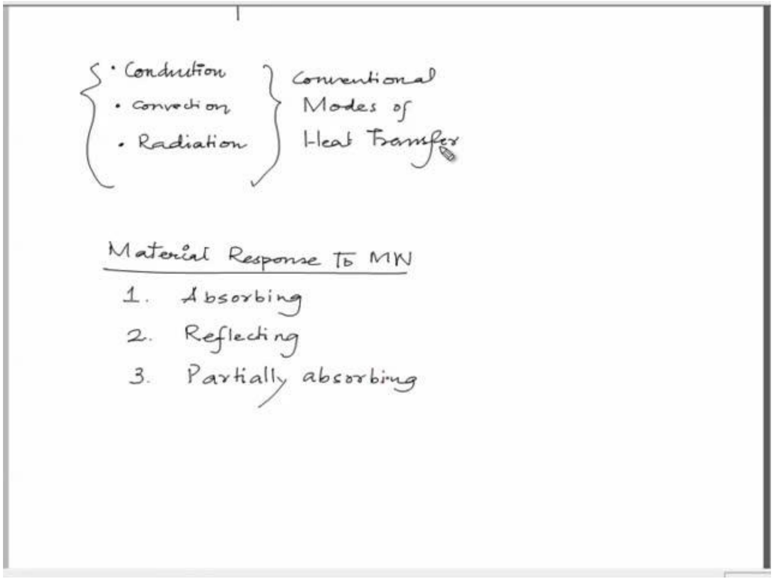

Material, one kind of material can be, material response to microwaves. One can be absorbing, one can be reflecting and one can be partially absorbing.

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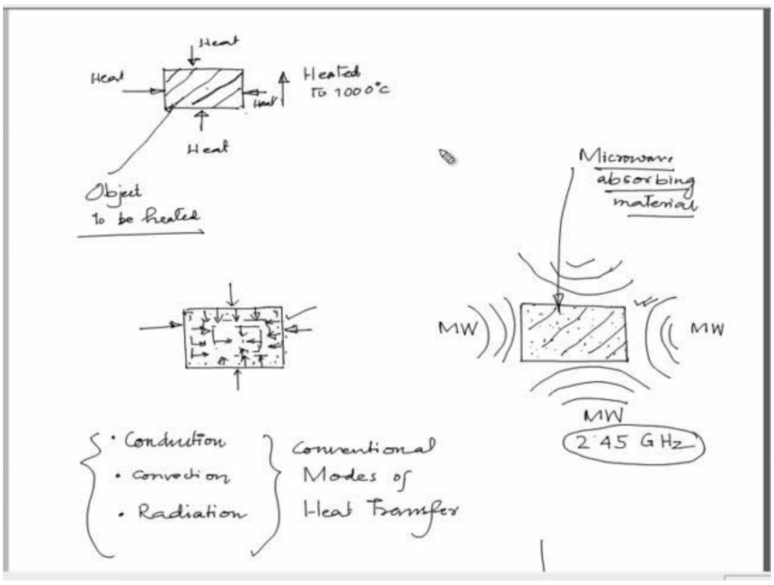

Now, let us consider that this materials is microwave absorbing material and we are subjecting this material to microwaves from say from all the direction, as we are doing in case of conventional heating process. So, this is nothing but microwave and it is at a particular frequency say 2.45 gigahertz. Now, if the material is microwave absorbing as we have already assumed, that it is then unlike we have seen in the case of conventional heating, were the heat moves, heat energy moves from the outer boundary of the material to the in inner boundary slowly like this.

Here, almost all the points or the volume of the material will get heated up almost simultaneously. That means, this phenomenon of getting heated layer by layer or transferring of heat energy from the outmost layer to the inner most layer does not apply in case of microwave heating here. Once it absorbs the microwave will get penetrated into and there will be molecular interactions with this microwave energy. Microwave as we know it is nothing but electromagnetic energy, it is a particular form of electromagnetic energy at a particular bandwidth of wavelength.

We will be using a particular selected frequency for processing or heating purposes, neither we will be allowed to do so. Means select our own frequency because of some other restrictions like some frequencies are continuously being used for communications, some others for some other purposes. Therefore, there are certain frequencies, which are being allotted worldwide for use in the material processing.

Now, once we use this microwave energy at a particular frequencies. Say for example, this then the molecules of this material will interact with this microwave energy. There are certain different mechanism say for example, if it is a water there will be a mechanism associated with with this. Like how the how the water molecules will interact with this electromagnetic waves and will get heated up. Similarly, if it is solid material, then the mechanism may be different, it is different and so on.

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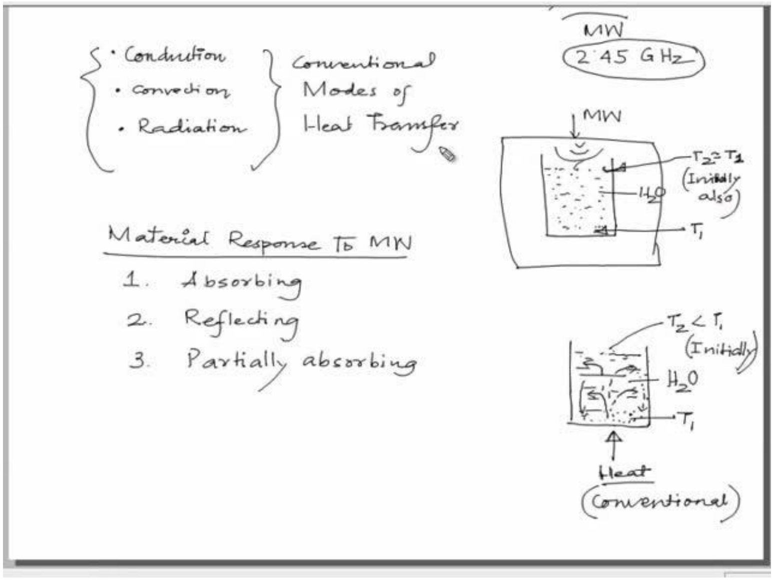

Therefore, we can assume that if I am keeping a cup of milk or water inside a microwave oven or if this is microwave oven chamber, in which I am applying microwave microwave. So, this is microwave, is microwaves are coming like this. Then I can I can say that this water is not getting heated up from here, rather it is getting heated up everywhere almost simultaneous at the same temperature. In contrary what would have happened, I would have heated up the same glass of water in conventional heating process?

Let us see what would have happen say for example, we are applying heat from bottom, then as we know the usual process of heating is like this. Then this water molecules will get hated up and they will try to move up, they will try to move up, they will try to move up and these cold molecules of cold water molecules will come down. So, this is the conventional way or very know process of water getting heating up in conventional heating. So, this is I can say, this is conventional heating conventional heating.

However, in case of microwave heating, this is same water. We can expect similar temperature at the same time, as in this layer as that of in this layer, unlike here. That is why in conventional heating process, although the temperature of this but at the bottom of this pot or the cup is high, this layer temperature will be much less initially. Say this is T 2 will be less than that of T 1. Initially this is what happens in conventional, but in microwave processing, this will be almost equivalent of T 1 sorry, T 1 even at the beginning.

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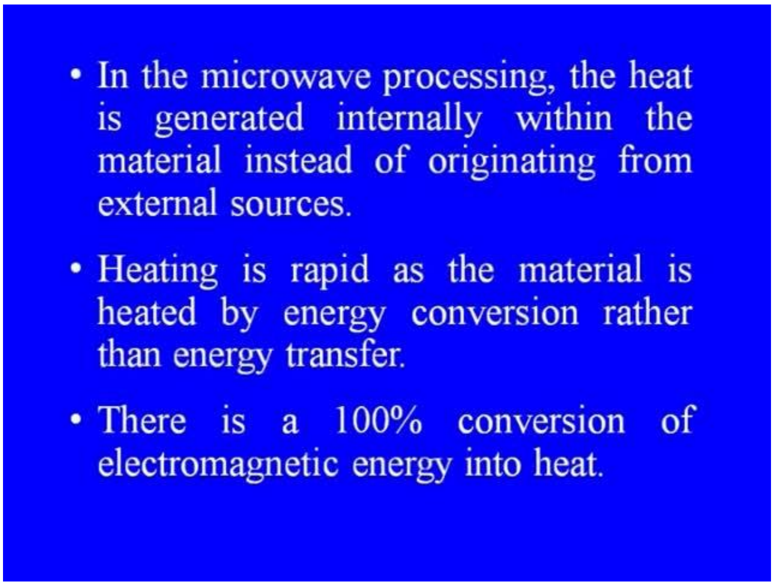

Initially also in microwave heating, heating is rapid as the material is heated by energy conversion, rather than energy transfer, this is what we have discussed now. In conventional heating it is rather energy transfer from molecules to molecule, but here this is rather energy conversion from electromagnetic form into heat form. There is a 100 percent convection of electromagnetic into heat. Therefore, loss is also very less and efficiency is high and that makes the process more economical.

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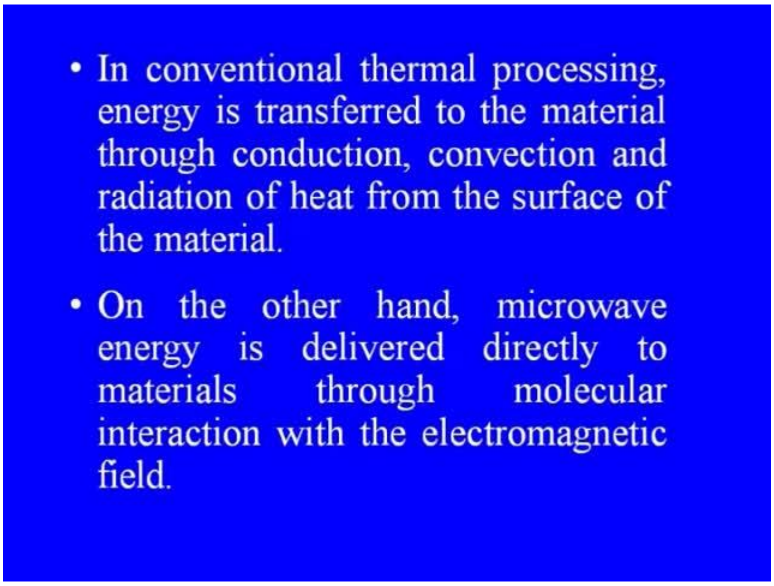

In conventional thermal processing energy is transferred to the material through conduction, convection and radiation of heat from the surface of the material inside. This is called, also called inside, outside in heating.

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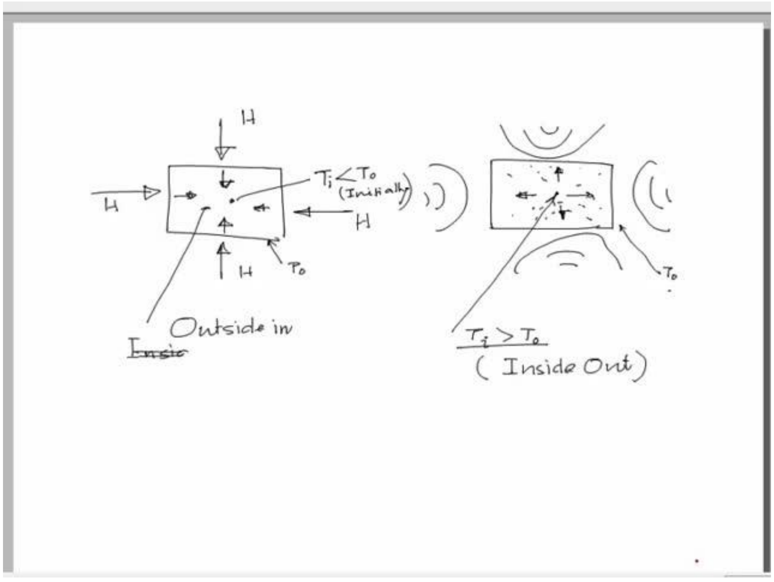

That is, so in this is, say heating. This is heat, this is called sorry, this is outside in on the other hand, if we are using microwaves. Then the energy will will enter or the electromagnetic radiations will enter inside almost simultaneously. The core temperature, the temperature here will be generally this temperature here. Say it is say T I, so this will be generally higher than that of T o, say this is T o; that is outside temperature. But here, if it is T o and if it is T I, so T i will be less than T o, this is initially.

This I have already explained. Therefore, because of this region, so this is also called also called inside out heating. That means if this temperature higher than that of outside temperature, therefore so heat will come while or will be transferred from this side to this side. Heat energy or heat flux will flow from outside to inside to outside, which is contrary to the outside to inside concept in conventional heating, as we have shown here. So, this is the basic difference in material processing using microwave energy. Microwave energy is delivered directly to the materials through molecular interaction with the electromagnetic field.

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This I have already indicated. Significant advantages in material processing through microwaves have been observed in respect of savings in processing time, product uniformity, grain size control and consequent property enhancement. Since, the material get heated up simultaneously through entire volume of the material, therefore it takes naturally less time to get heated up and therefore, consequently less energy will be required. One more important thing is, the product will get heated up uniformly.

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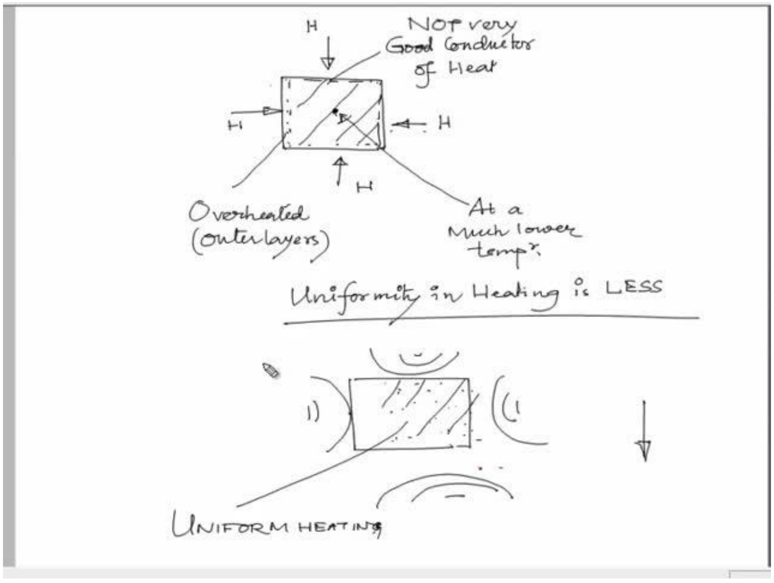

In some cases say for example, suppose a product is like this and and this material is not very good conductor of, good conductor of heat not. Then what will happen, if we apply heat from all the sides, let us let us for uniformity check, let us consider that we are applying heat from all the sides and uniformly. Then by the time this point attains a temperature, which is considerably high, this outside temperature or the outside layer, these layers under the entrance of this heat may get over heated. There is a chance of getting overheated this outer layers.

On the other hand, this point may be at a much lower temperature, that means the uniformity in heating uniformity in heating is less. However, in case of microwave heating, since the entire object will be heated up almost simultaneously, as I have told already at the same time. Therefore, I can say the temperature of in this, inside this body will be almost uniform and this will be uniform heating and the possibility of this outer layer getting overheated will be reduced. Therefore, we can expect better product quality in microwave heating.

Microwave energy has been in use for variety of applications for over 5 decades. However, in the last few years more advancements and applications like, ceramic sintering were noticed. Of late of course microwaves have been applied very effectively for processing materials also.

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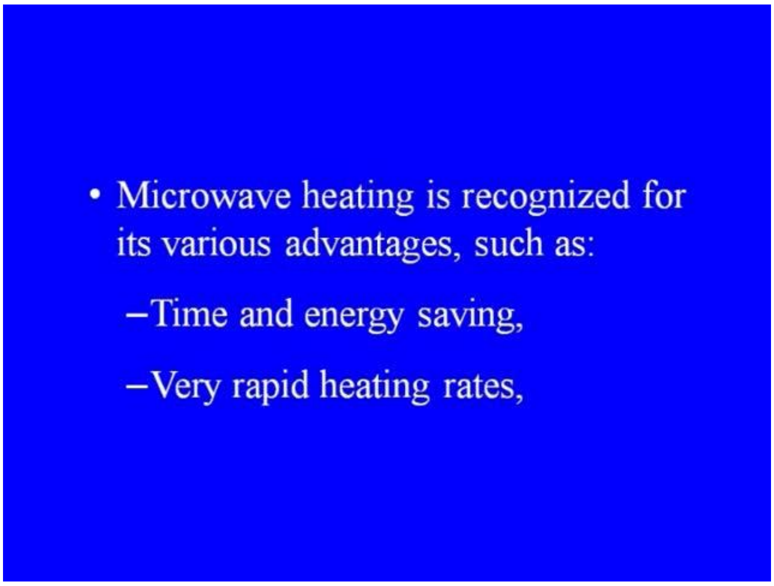

Microwave heating is recognized for its various advantages, such as time and energy saving, very rapid heating rates.

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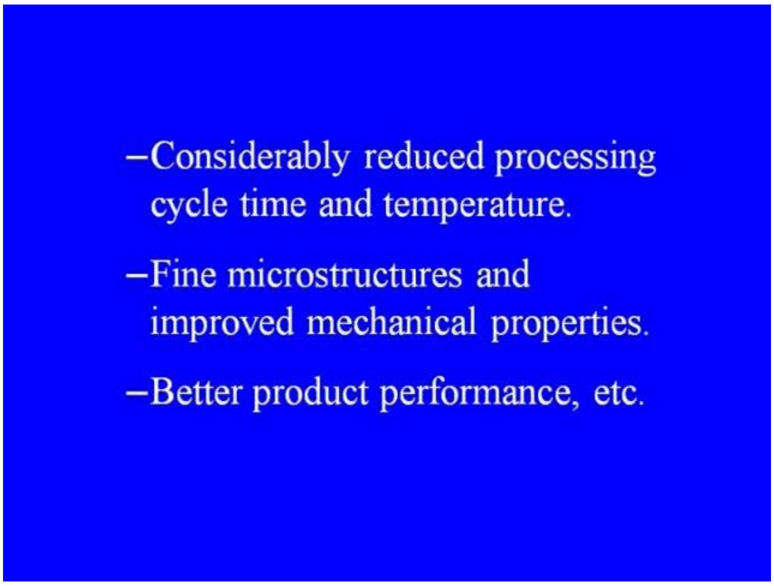

Considerably reduced processing cycle time and temperature. One can obtain fine microstructures and improved mechanical properties. Then better product performance etcetera. We can control, this is one of the significant aspects of microwave processing, that we can control the microstructure of a product. Say for example, as we know the microstructure of a product, often heating or cooling, basically it depends on the rate of cooling and rate of heating, which we can control in a better way in case of microwave heating because it will be uniform.

Therefore, there is a most likelihood that, the microstructures will be informed throughout the volume of the, or the bulk of the body being heated or being processed. Therefore, consequently it will result in uniform mechanical properties, which we can control in a better way. In case of electromagnetic energy, which is nothing but microwaves.

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The most recent application microwaves has been in the field of metallic materials for sintering brazing joining melting and cladding and so on. Several common steel compositions pure metals and refractory metals have also been sintered in microwaves to nearly full density with improved mechanical properties. Why the mechanical properties could be improved, that I have already indicated. If we can have better control over the formation of microstructures, then we can expect better properties. Rather we can design better mechanical properties by designing the appropriate microstructures; that may correspond to that particular properties. This is one of the very significant advantages of using microwaves in material processing.

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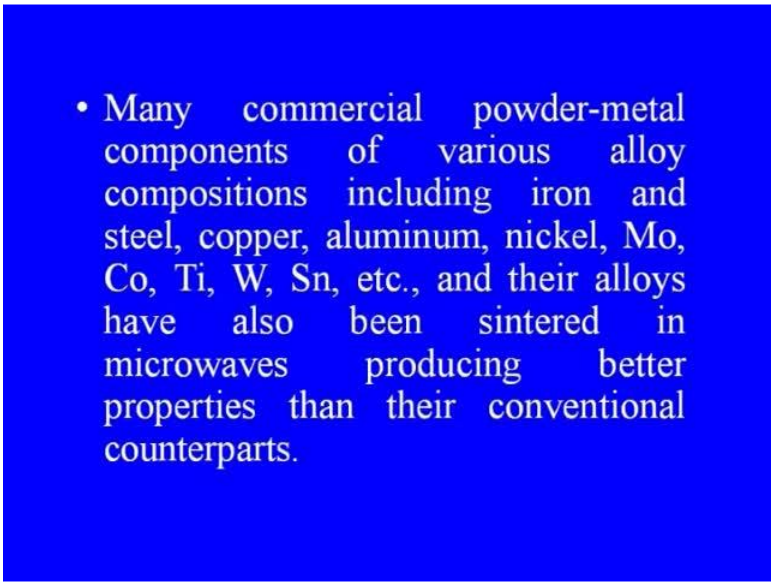

Many commercial powder metal components of various alloy compositions including iron and steel, copper, aluminum, nickel, molybdenum, cobalt, titanium, tungsten, tin etcetera and their alloys have also been sintered in microwaves producing better properties than their conventional counterparts. We will see in another session, how this sintering can cause better properties and how the researches different researchers have experimented on may on this and they have obtained some results.

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Few years back, metals were earlier, metals were considered not viable to process through microwaves, owing to the fact they primarily reflect microwaves at room temperature.

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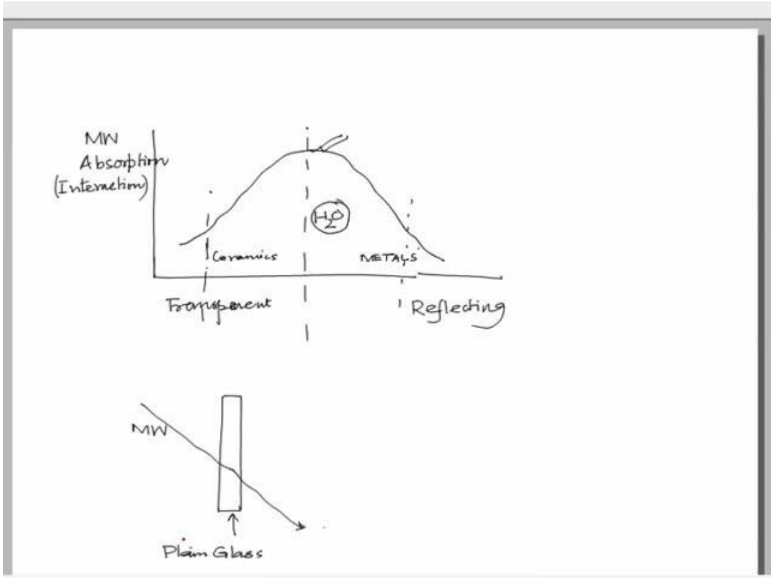

This can be explained like this, generally as far as the microwave absorption of absorption of microwave by different materials are concerned, this can be expressed in terms of, or explained in terms of a bell curve, very conventional bell curve. So, in these two, if we talk about microwave absorption or interaction or we can say interaction with different materials, then these two are the extremes and this is the maximum absorption. Here in this zone, there are materials like water etcetera falls. Therefore, that is why in most of the home applications food preparations, what we find most of the food materials contains a very good amount of water.

Although we may recognize it or may not recognize it. In few preparations, we intentionally add water or in few many food grains or food materials food items itself it itself contains a very good quantity of water, like potato. Although it is a solid material, but it has got quite a good percentage of water in it, inside it. This water is playing a very vital role in getting this potato heated or cooked. So, is the case in other food materials like where we add intentionally water. So, this water gets heated or rather interacts with microwave get heated and in turn helps in cooking the food stuff.

So, this in this, middle of this the peak of the microwave absorption or interaction, one significant material that is water. These two extremes we have in one side, we have ceramics most of the ceramics, so there we can say almost transparent and in this in this side they are metals, which are almost reflecting. That is why, these two categories of materials, one is transparent, that means like glass, plain glass. We can pick help of say a plain glass and microwave energy falling on it is simply going out. Said, say this is like a glass, plain glass plain galss.

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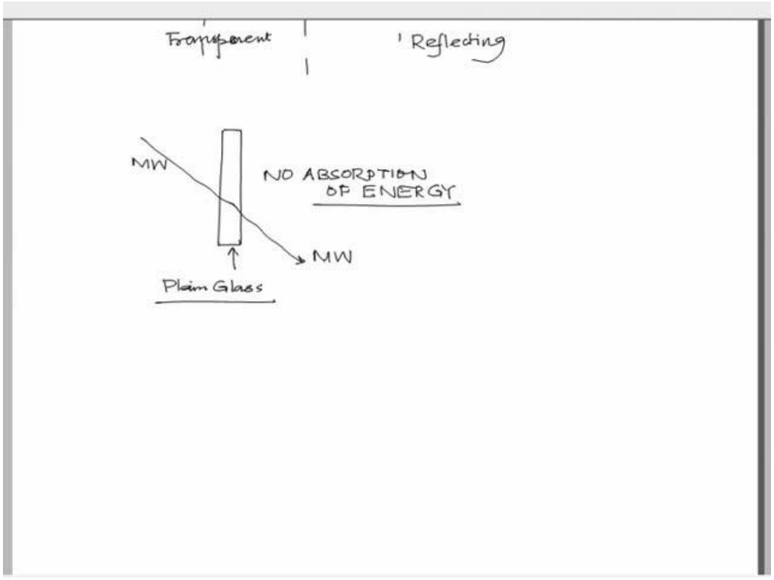

It is coming and going out that means there is no absorption absorption of energy, if there is no absorption of energy, who will do the work? That means to get some work done, we need energy and that energy must come from the electromagnetic waves. If it is completely transparent, then we do not have any energy to work it done or get it heated. Therefore this matter this kind of materials are difficult to process through microwave.

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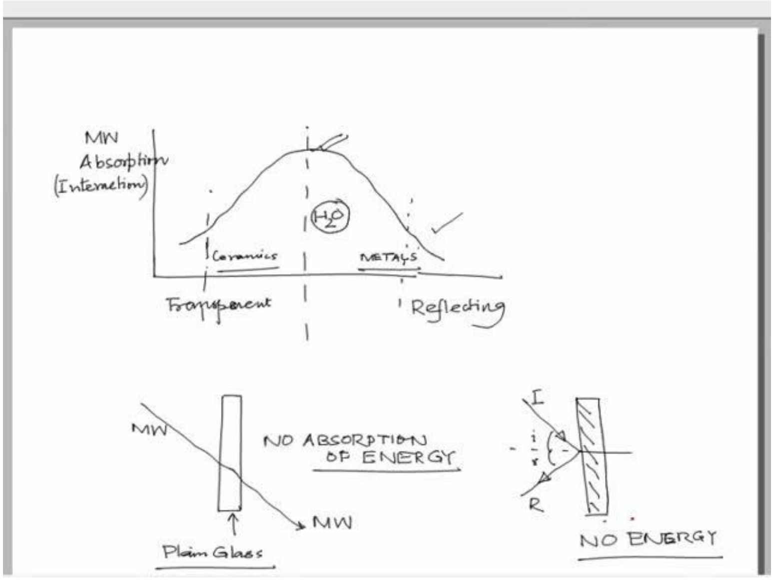

At the same time if we consider these metals, they are simply like mirrors. Mirrors to normal light, what they do? As we know, so the if this is the incident light, this is the reflected light, with the laws of whatever the reflection is. That means in this case also, if the material itself is totally reflecting, then there is no energy, no energy being absorbed for processing the material or in turn we can say for heating materials. Thus there are challenges in processing, these two kinds of materials, which do not absorb microwave energy directly.

However, it is seen that ceramics do absorb microwaves at certain higher temperature, that is specific to its own metal properties. That is how the ceramics are being processed by using microwaves vary widely, but metals for that matter were not researched out or investigated. That they can also be processed by some other means with the aid of microwaves energy or electromagnetic energy. Recent research activities indicate, that it is possible to process metallic materials including powder metals, pure metals and alloys under certain conditions, in a 2.45 gigahertz microwave field/

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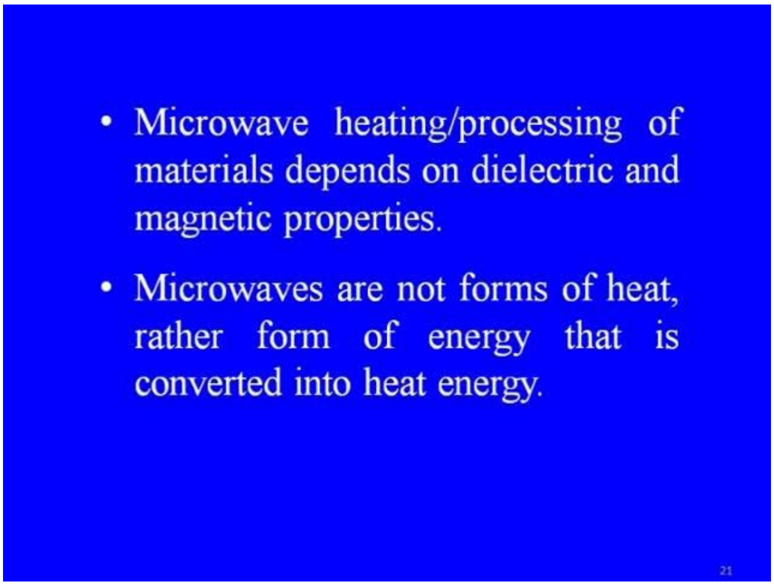

Microwave heating or which also we call as microwave processing of materials depends on dielectric and magnetic properties of materials. Microwave heating is not only the processing, in certain cases like say chemical processing or some polymeric processing, it not necessarily result in heating like certain chemical processes. The reaction rate gets enhanced because of the exposure to microwave energy. Some polymer, in case of some polymers curing get enhanced, because of the processing of the or exposure to the microwave energy.

Therefore, in these cases we can say, it not necessarily result in heating, but we can term very well them as processing. Microwaves are not forms of heat rather than form of energy, that is converted into heat energy, this is very important concept. We have spoken about microwave and its affect on different materials. Now, let us quickly brush up what microwaves are basically. We have spoken several times the microwaves are electromagnetic waves, with the wavelengths in the range of 10 millimeter to 300 millimeter, as all of us we know there is a electromagnetic like spectrum, in which wavelengths are we can represent different rays or different energies in the, in terms of wavelengths that we will see pictorially as well.

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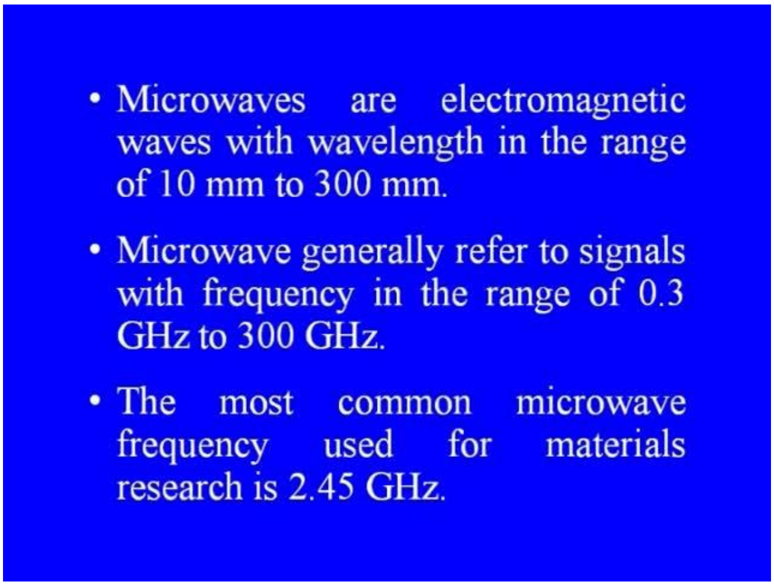

Microwaves generally refer to signals with frequency in the range of 0.3 gigahertz to 300 gigahertz. this is characteristically the spectrum within which we consider the microwaves, the electromagnetic radiations to be microwave. However, the most common microwave frequency used for materials research is 2.45 gigahertz, as I have already indicated.

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The federal communications commission have issued the industrial scientific and medical frequency bands used for industrial microwave heating this frequencies are indicated in this table you can see.

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Table-1 Permitted Frequency and wavelength bands

Frequency (MHz)	Wave length (m)	Area Permitted
896	0.32	Great Britain
915	0.33	North & South America
2450	0.122	Other parts including India

Frequency 896 megahertz in the wavelength range of 0.32 meter. So, this is also being permitted for use in material processing, this is being used almost in the area like Great Britain etcetera. Then another frequency permitted is 975 megahertz in the wavelength corresponding wavelength 0.33 meter, which is used in North and South America. Basically and another one is 2.45 gigahertz or 2450 megahertz in the wavelength range of 0.122 meter or 12.2 centimeter and this is being almost used worldwide or we can say except America and North South America or Great Britain, all other parts frequency is being popularly used.

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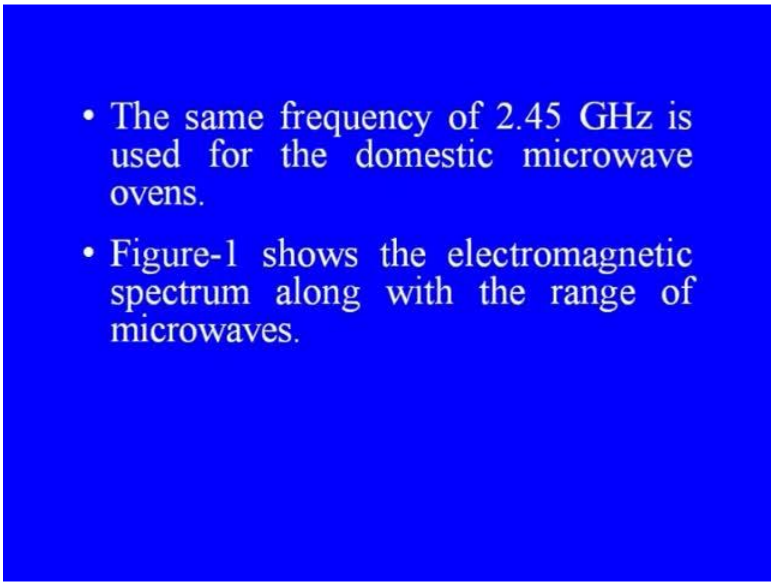

The same frequency of 2.45 gigahertz is used for domestic microwave ovens also. Nowadays, microwave ovens are no wonder for any domestic a kitchens also. It figures in almost all kitchens. This figure shows, as I was taking about the electromagnetic spectrum.

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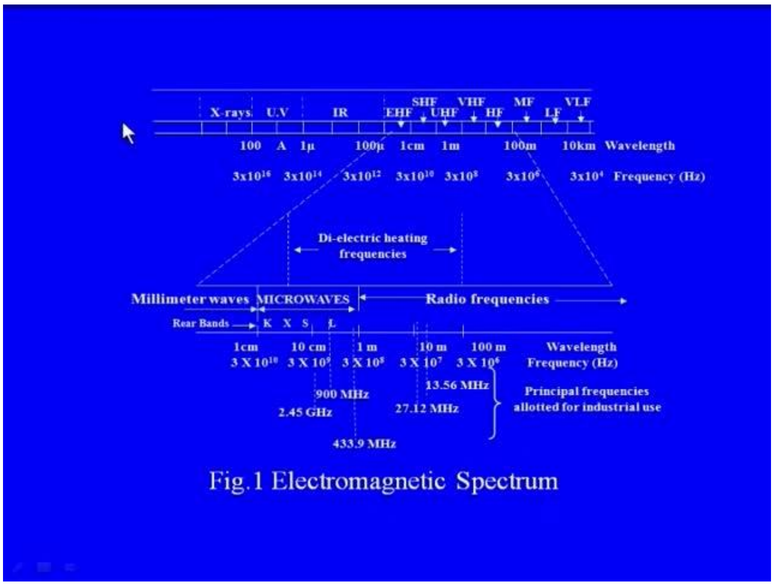

Fig.1 Electromagnetic Spectrum

So, here in this screen one can see, so this is the entire range of electromagnetic spectrum, which can be divided into different useful form. That is in this range this is X rays, which are being used in various applications from materials characterization to health care or medical diagnosis system. It is very useful tool or very useful form of energy. Then UV and IR, they are also in used in different applications like IR imaging is there. IR imaging is coming in a very big way, then this is the range where we we use for communication etcetera.

Ultra high frequency and high frequency etcetera and then there are there are some more high frequency wavelengths, high frequency electromagnetic radiations. Inside this, in this range as I have already pointed out, 0.3 to 300 300 gigahertz, this is the range for microwaves. So, this comes in this range of thus 1 centimeter to almost 1 meter. So, this is the range were we often return and in this band are used for, some frequencies are used for communication. Only this few, say 2.45 gigahertz say then 9.15 giga megahertz and this they are being used.

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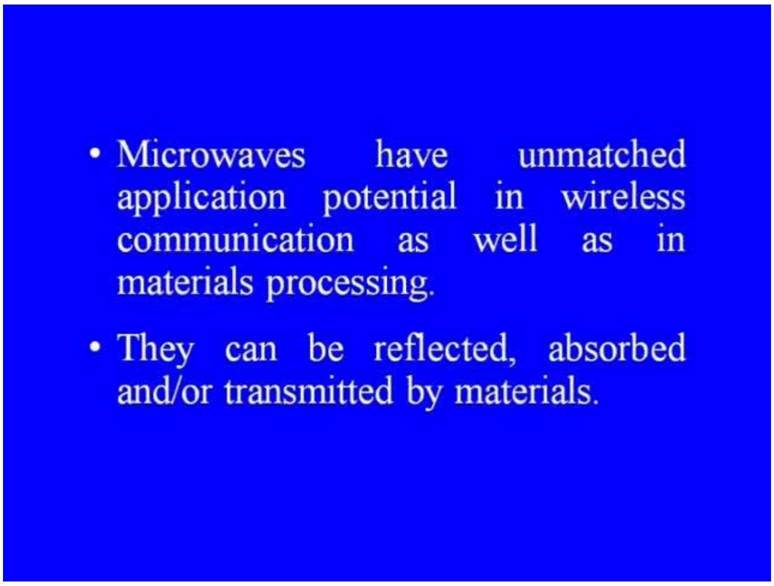

For microwave heating purposes or for industrial purposes microwaves have unmatched application potential in wireless communication as well as in materials processing. They can be reflected absorbed and transmitted by materials.

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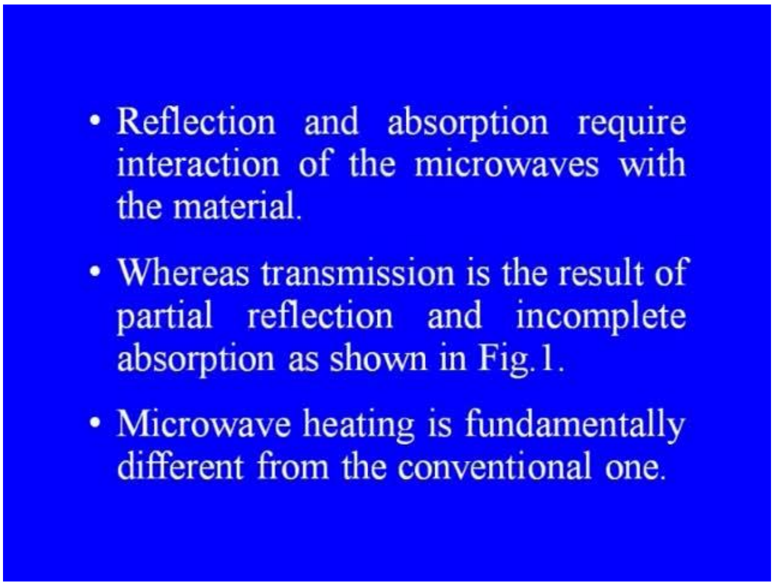

This I have already discussed. Reflection and absorption requires interaction of microwaves with the material, whereas transmission is the result of partial reflection and incomplete absorption. This we will see in terms of another figure.

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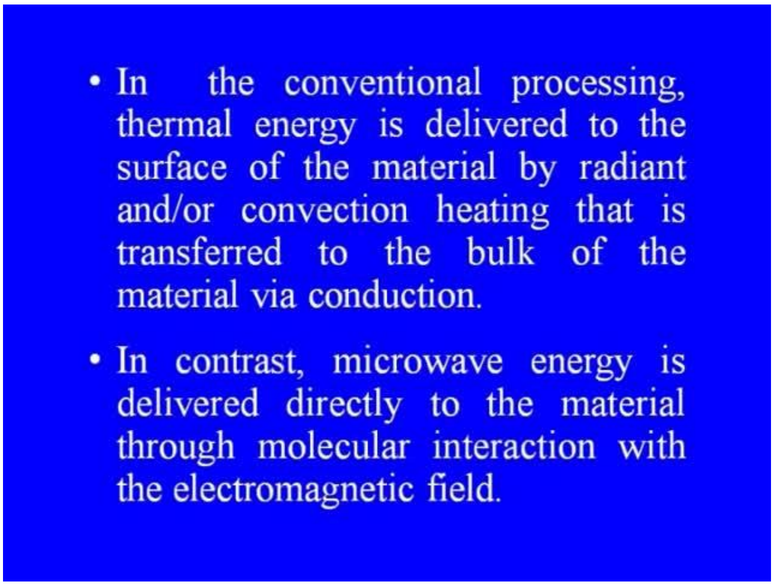

In the conventional processing thermal energy is delivered to the surface of the material by radiant and or convention heating, that is transferred to the bulk of the material via conduction. In contrast microwave energy is delivered directly to the material through molecular interaction with electromagnetic field.

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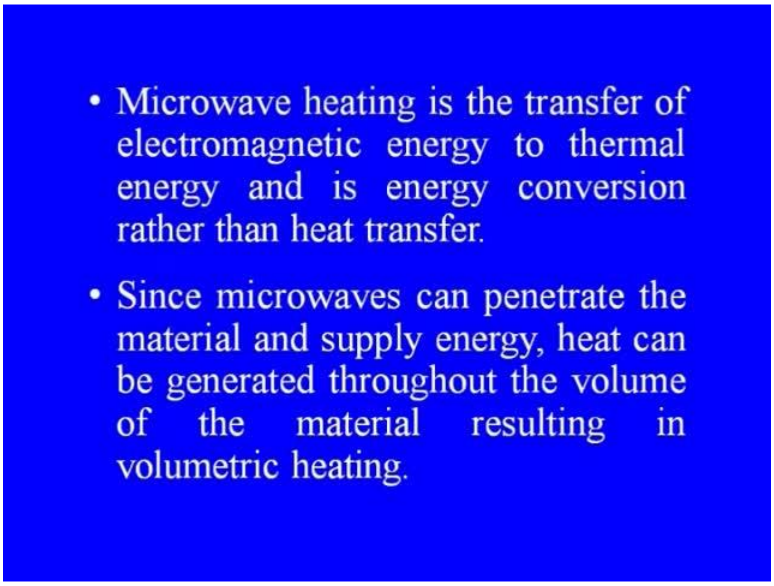

Microwave heating is the transfer of electromagnetic energy to thermal energy and is energy conversion rather than heat transfer. Since, microwaves can penetrate the material and supply energy heat can be generated throughout the volume of the material, resulting in volumetric heating, this I have already discussed. How the entire volume of the material can get heated up because of this purposes. Once the material is absorbing material off course, otherwise either the material energy pass through it or it will totally reflect back, without giving any chance to work with. That means that is heating it or doing some other work.

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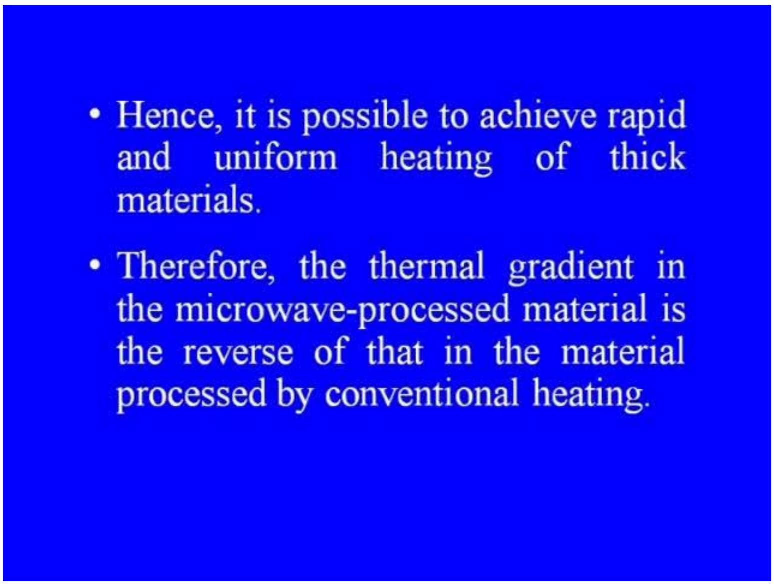

Hence, it is possible to achieve rapid and uniform heating of thick materials as well. Therefore, the thermal gradient in microwave processed material is the reverse of that in the material processed by conventional heating, which I have already shown as outside in and inside out concept.

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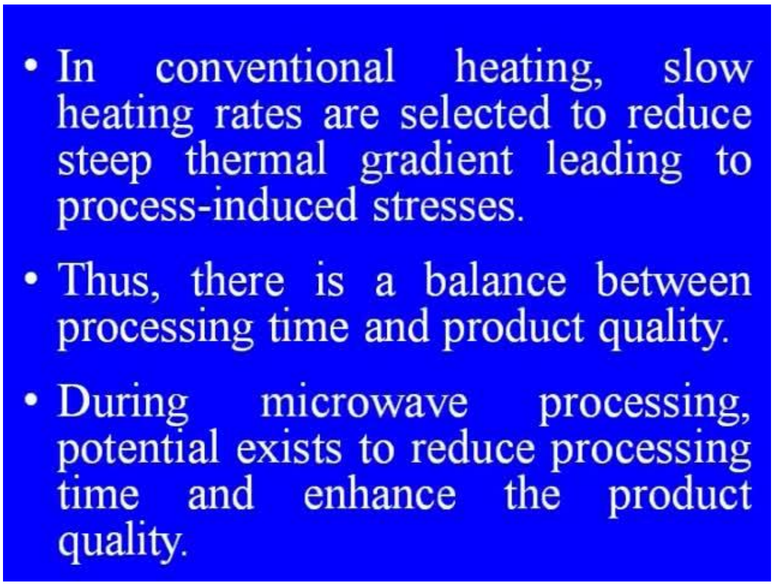

In conventional heating slow heating rates are selected to reduce steep thermal gradient leading to process induced stresses. Thus there is a balance between processing time and product quality. During microwave processing potential exists to reduce processing time and enhance the product quality.

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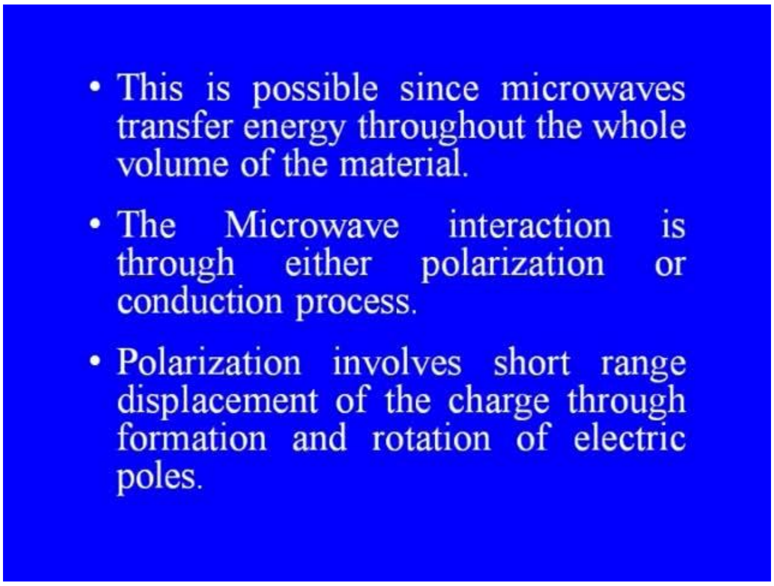

This is possible since microwaves transfer energy throughout the whole volume of the material. The microwave interaction is through either polarization or conduction process. The polarization involves short range displacement of the charge through formation and rotation of electric poles.

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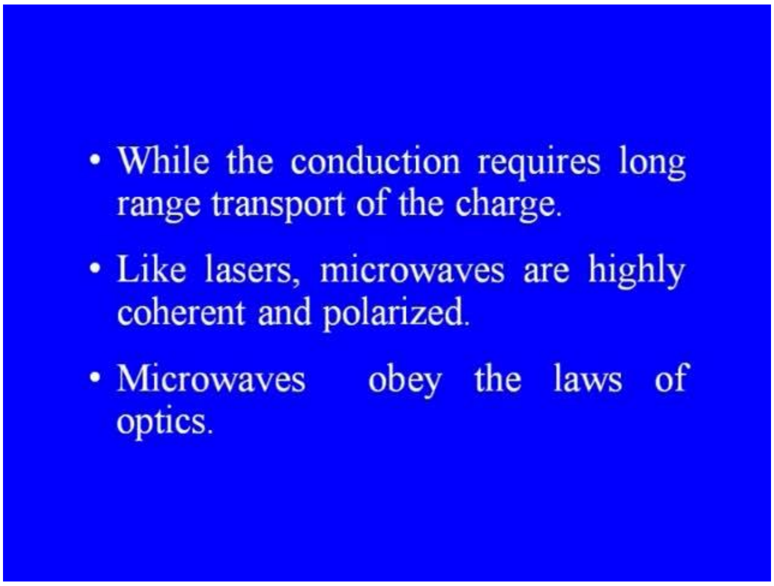

While the conduction requires long range transport of the charge, like lasers, microwaves are highly coherent and polarized. Microwaves obey laws of optics. As I I have already indicated.

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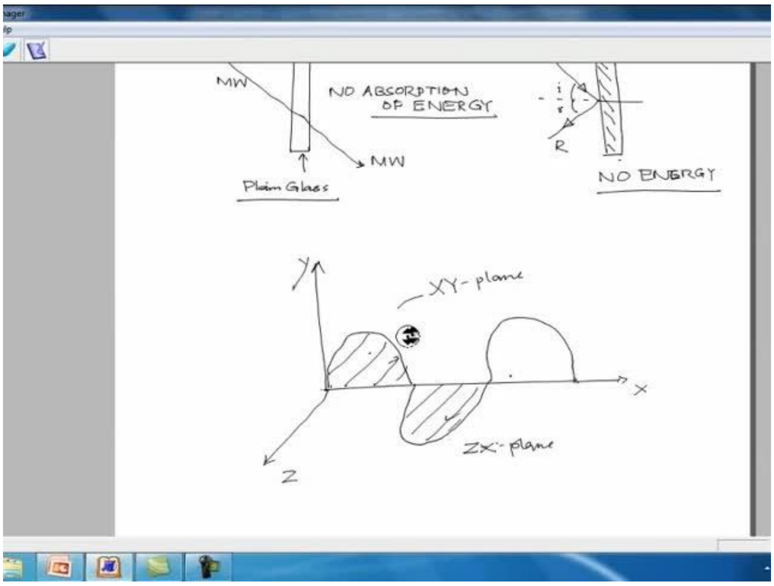

So, microwaves, since their electromagnetic radiation, they have two components in two different, say two orthogonal planes. So, this is say this is X, this is Y and this is Z. Then one component is in, so this is the X Y plane X Y plane and other component will be in say Z X Z X plane. That means one is electrical component and other one is magnetic component. So, they are, but orthogonal to itself.

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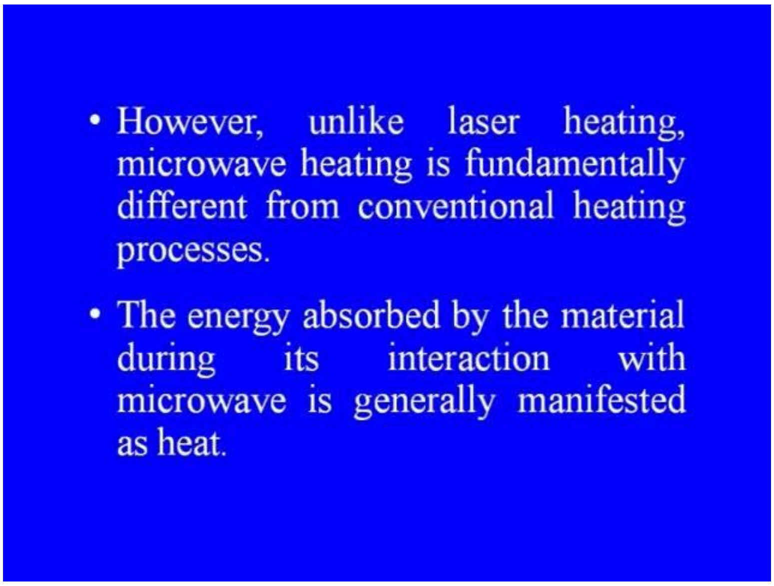

However, unlike laser heating, microwave heating is fundamentally different form conventional heating processes. The energy absorbed by the material during its interaction with microwave is generally manifested as heat.

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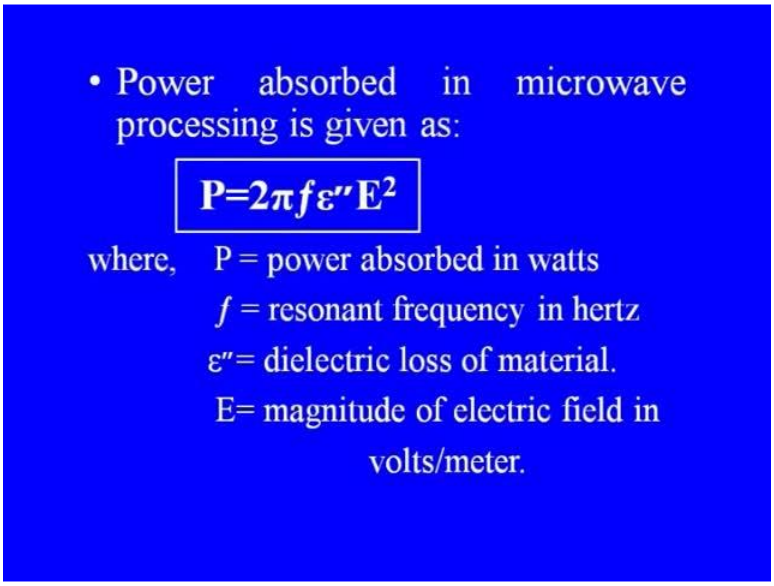

The power absorbed in microwave processing is given by P is equal to 2 pi f epsilon double prime E square, were power is the expressed as P, f is the resonant frequency in hertz, epsilon double prime is the dielectric loss of the material and E is the magnetic, magnitude of the electric field in volts per meter.

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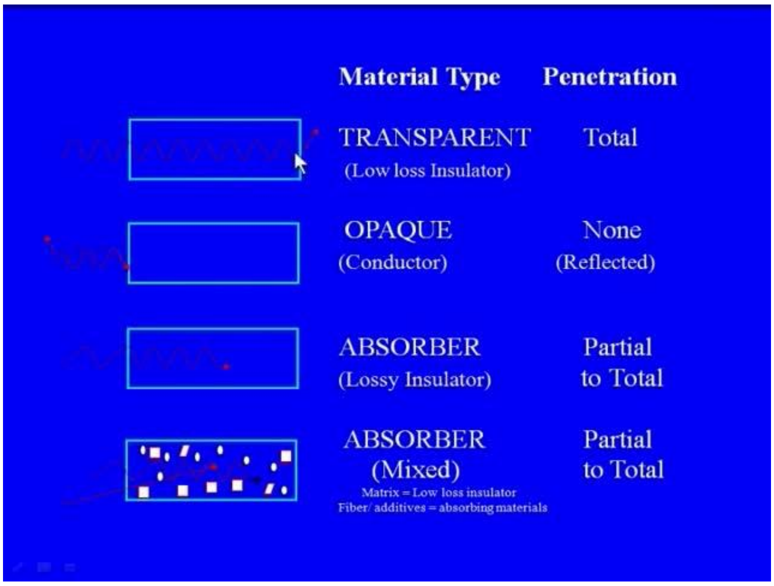

So, this is the symmetric of how electromagnetic rations, like microwaves interact with different materials. In case of, as I have already talked about, which are low loss insulators the energy will simply pass through. In case of opaque materials, which are conductors so they will simply reflect back the microwave radiations. In case of absorber, they will get absorbed inside this volume of this material.

Some materials if we, if they are say basically transparent, but we mix some absorbing material inside this. Say these are the second phases, then because of the presence of this second phase, this microwave energy will be absorbed by the second phase and get heated up and that heat energy will be given to the first phase, which is basically transparent. So, this can be we can say, this is a mixed absorbing system or the partial to total absorption can take place.

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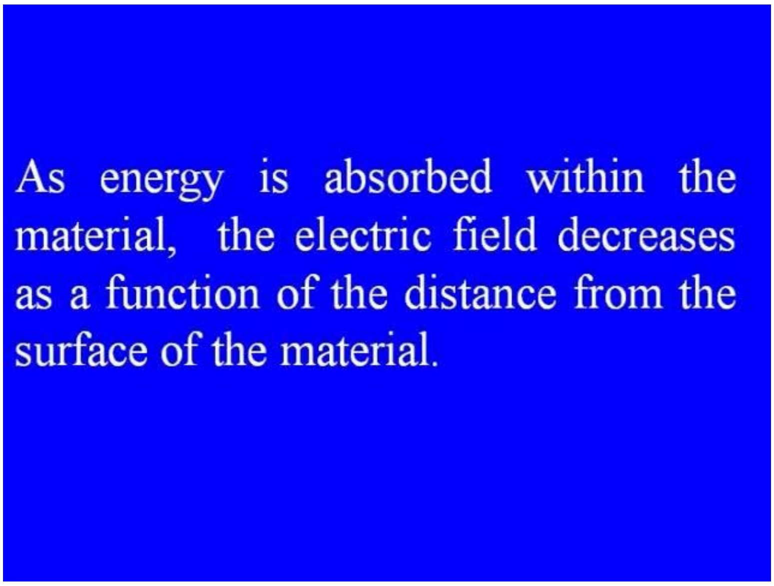

As energy is absorbed within the material the electric field decreases as a function of the distance from the surface to the material.

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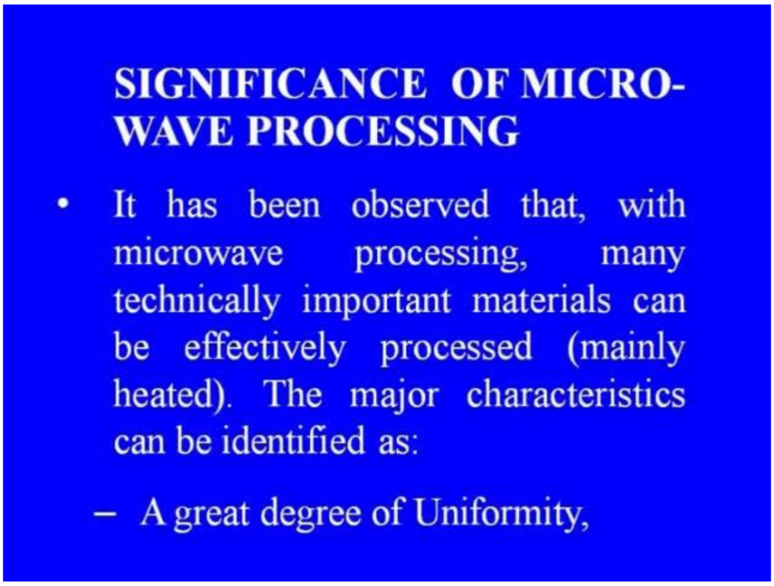

Significance of microwave processing it has been observed that with microwave processing, many technically important materials can be effectively processed, mainly heated. The major characteristics can be identified as a great degree of uniformity.

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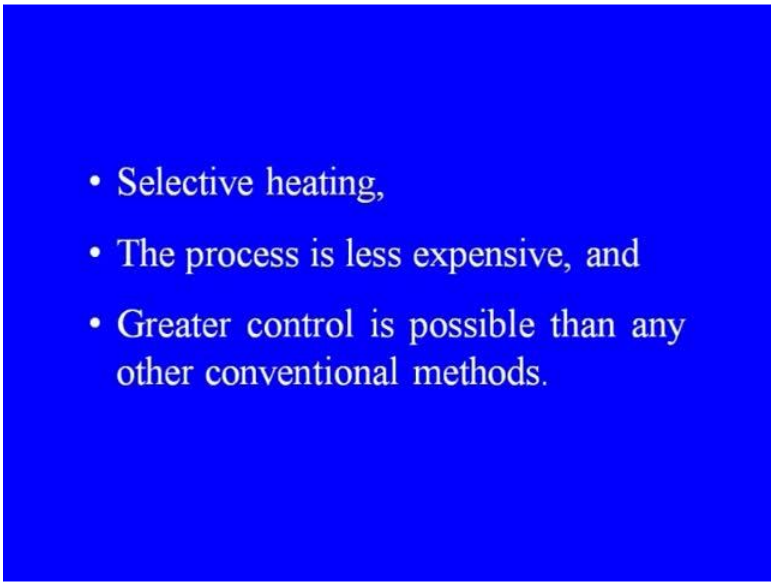

Selective heating, the process is less expensive and greater control is possible than any other conventional methods. Now, let us quickly look at the limitations and challenges of microwave processing of materials.

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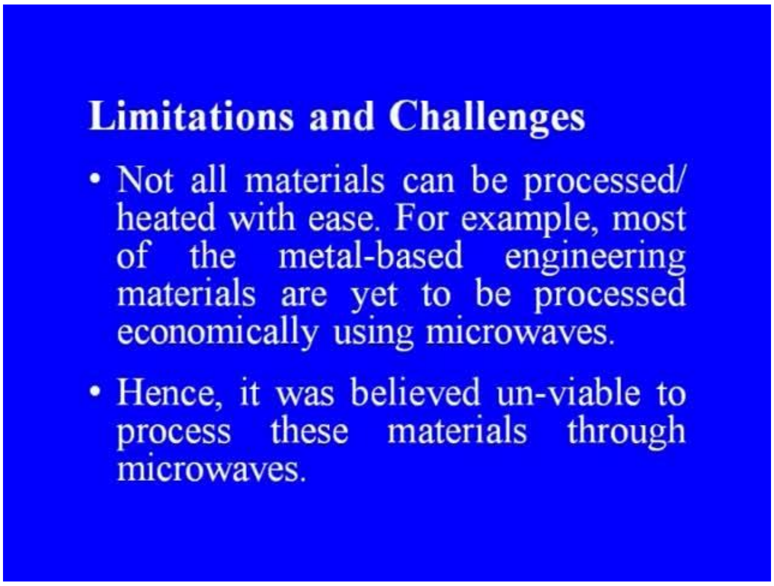

Number one, not all materials can be processed or heated with ease for example, most of the metal based engineering materials are yet to be processed economically using microwaves. Hence, it was believed unviable to process these materials through microwaves.

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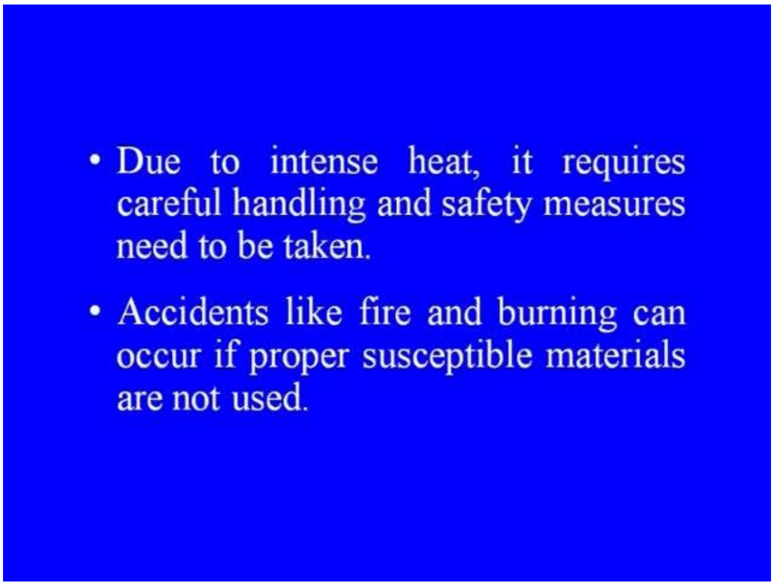

Due to intense heat it requires careful handling and safety measures for the operators as well as for the systems. Accidents like fire and burning can occur if proper susceptible materials are not used. Now, let us quickly list the advantages advancements and future prospects.

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Considerable developments in this area have been have taken place in the last two decades. Today microwaves are being extensively used in industrial heating and processing of processing applications. We will see some more advancement and future prospects and applications in the next session.

Now, let us summarize what we have discussed in this particular session, a relatively new material processing technique, a very advanced material processing technique. That is microwave material processing technique have been introduced, its features and advantages are also being discussed. Applications and future trends of this technique have also been indicated. We hope this was a new learning experience and the discussions were interesting.

Thank you.