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Advantages and Limitations Regarding the Processing of Materials in Concentrated Energy Solar Furnaces

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Abstract
Solar energy is already widely used for water heating and electricity production. Attempts to process materials with solar energy have been made since the 17th and18th centuries. The construction of high and medium power concentrated solar furnaces in the late 20th century opened new perspectives in this direction. Lately, the possibilities of processing materials by using this energy are being researched more and more, together with the construction principle and the features of the operation of solar furnace with concentrated energy. Based on the knowledge gained in research conducted worldwide by various authors, including the University of Transilvania in Brasov, an analysis is made of the advantages and limitations of various processing of materials in such ovens, taking into account the possibilities of application at the industrial level.

Keywords
materials processing, concentrated solar energy, solar furnace, surface hardening

1. Introduction

In recent decades, great progress has been made in the development of new materials capable of working in extreme conditions. These advances are related to the development of nuclear and space techniques, but also to the desire to increase the reliability and durability of manufactured products.

As a result, new materials processing techniques have been researched and developed, based on high-density energy beams (laser, plasma, ion or electron beam, electric arc, solar energy). Applied to the surface of parts, to change the properties of metallic materials, they can stimulate transformations in the structure, leading to advanced equilibrium or nonequilibrium microstructures with superior properties. For example, high resistance to corrosion, oxidation, wear, dimensional and structural stability to temperature variations, etc.

2. The Object of the Paper

The construction and commissioning of high and medium power concentrated solar ovens since 1950, but especially after 1970, (when the large 1MW solar furnace was put into use in Odeillo, France) opened new directions for research on the processing possibilities of materials with high energy flows and very high temperatures [1, 3-16].

Since 2008, the European Community has launched the SFERA (Solar Facilities for the European Research Area) research program on the use of solar energy. Given the possibilities offered by this energy source, the scientific community has recently approached more and more research on the processing and testing of materials with concentrated solar energy.

Previous work has provided an overview of the state of construction of solar furnaces and various material processing [1, 2, 3, 6]. The papers present the experienced processing and the results obtained. The possibilities, results and advantages of using solar energy are shown, but the limitations or disadvantages of using these ovens are not mentioned. However, it is known that all installations used in industry or research for the thermal processing of materials have limitations and disadvantages in implementation. Research has shown that solar ovens with concentrated energy have limitations and disadvantages related to material processing. This paper aims to highlight and discuss the advantages and disadvantages of using solar ovens related to the possibilities of processing materials at the industrial level. Starting from the particularities of the operation of solar furnaces with concentrated energy for materials processing, an analysis of the limits and disadvantages involved is made.

3. Construction of Solar Furnaces with Concentrated Energy

Solar furnaces are of two types:

- with mirrors, which concentrate solar energy by reflection;
- with lenses, which concentrate solar energy by refraction.

There are large differences in construction and total possible power between these two types. Furnaces with refraction concentration (with lenses) have a simple construction, but their power is lower, being limited by the possibilities of making lenses with a very large diameter. They receive energy directly from the sun and as a result the power is limited by the diameter of the lens.

Depending on the positioning of the concentrating mirrors, the mirror furnaces have a horizontal spot and a vertical spot. In these furnaces, the sun's rays are received by flat mirrors (heliostats) and reflected to a parabolic (or spherical) mirror that concentrates them in the focus, where the target to be heated is placed. High power ovens (700 - 1000 kW) have a horizontal spot axis because the concentrating mirrors have very large dimensions (up to 50 m in diameter). The construction of such mirrors with a vertical axis would be difficult to achieve. Figures 1, 2 and 3 show the principle of construction of the three types of furnaces.

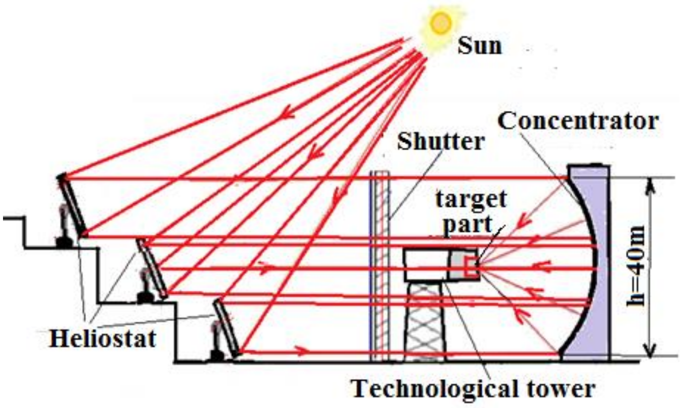

Fig. 1. High power horizontal solar furnace (construction scheme)

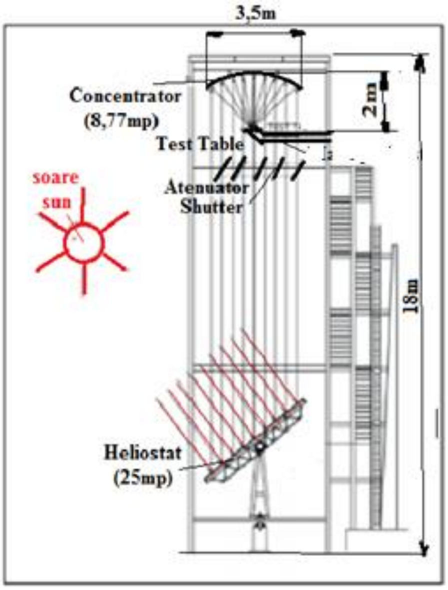

Fig. 2. Medium power vertical solar furnace, construction scheme [2]

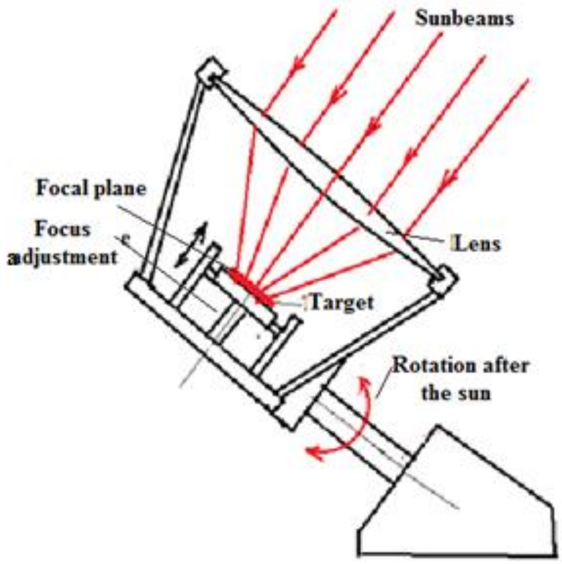

Fig. 3. Solar furnace with lens, construction scheme

The main features of the operation of solar furnaces with concentrated energy are:
- inexhaustible source of energy,
- zero cost of energy at source,
- low maintenance and operating costs.
- reduced wear of operating components,
- low negative impact on the environment,
- high power density on the incident surface,
- the possibility of continuous and prompt control and adjustment of working power,
- clean working conditions and the possibility of working in protective atmospheres,
- accelerating and intensifying transformations,
- heating the part through a single surface, in the focal plane of the concentrator,
- the surface of the energy transfer to the part is limited to the diameter of the spot in focal plane.

Most published papers mention as an advantage that the sun is an unlimited source of energy in time, and the cost of energy at the source is zero.

Solar furnaces receive photon energy that reaches the earth in the form of radiation from the sun and concentrate it on the opaque surface of the target to be heated. This is placed in the focal plane of the concentrator. On the surface of the part, the kinetic energy of the photons is instantly transformed into thermal energy, raising the temperature of the receiving surface, quickly and to very high values. The part is heated in volume by thermal conductivity. The temperature and heating time of the parts depend on the power density incident on the surface of the part. The power density depends on the total power of the installation, and this depends on the total energy received from the sun by heliostats (so the total surface of the heliostats and the intensity of solar energy incident on the earth). In the focal plane, temperatures can be reached on the target surface very high in a very short time (possibly 3000 - 3500 °C in a few seconds) [1, 3]. An important effect in the processing of materials is also the direct interaction of photons with the atoms of the material. This can stimulate microstructural transformations that do not occur when heated in conventional furnaces.

Solar furnaces allow heating in transparent, airtight, quartz reactors. It is possible to heat the parts in an atmosphere and under controlled pressure. The dimensions of the heated surfaces depend on the power of the furnace, but especially on the diameter of the spot concentrated on the surface of the parts. In the case of existing installations, surfaces of the order of 0.5-1.0 cm can be heated quickly and relatively evenly for a 1-2 kW solar oven and 20-30 cm for 0.7 - 1 MW solar ovens. The thickness of the heated layer on the surface of the parts depends on the exposure time and the thermophysical characteristics of the materials.

Solar installations allow quick control and adjustment of working parameters and therefore of material heating. The heating speed can be adjusted and changed practically instantly, with the help of flap attenuators. These are part of the construction of high and medium power ovens. They can be operated manually or automatically - programmed.

4. Analysis of the Advantages and Limitations of Materials Processing in Solar Furnaces

4.1. Energy availability over time

It should be emphasized that the "infinite availability in time" of solar energy refers to the availability of energy at source and not at the user. For application in industry or for domestic use, however, the availability of energy to the user is important. In the case of solar energy, it has great disadvantages, being limited in time and location. Solar energy can only be used on sunny days and a limited number of hours per day. That is why the existing solar furnaces have been located in areas that benefit from a large number of sunny days per year (statistic 270-300). Even if the receiving mirrors (heliostats) rotate after the sun to reflect the sun's rays towards the furnace concentrator (which is fixed) the solar energy can be used on sunny days (close to the maximum power value) for a maximum of 6 - 7 hours a day. The angle of incidence of the sun's rays on the earth is constantly changing. Therefore, the received power changes all the time, being maximum only at the apogee. Regarding the availability of solar energy to the user, we can give as an example, a recent situation at one of the solar platforms in Europe. A researcher from the Transilvania University of Brașov travelled to one of the solar platforms in Europe in order to carry out experiments in a European project. For seven consecutive days, it was not a sunny enough day to carry out the experiments. Therefore, the experiment did not take place.

4.2. Energy availability in location area

There are two recommendations regarding the location of solar ovens. They should be built in warm areas (equatorial or subequatorial) so that the angle of incidence is as small as possible and in areas as high as possible (at high altitude) so that the air is rarefied and clean. As a result, the existing high and medium power solar furnaces, which work by reflection, have been located in mountainous areas, at altitudes above 1100 m. However, there are also facilities built in large cities next to universities or research institutes (e.g. lens installations at the University of Castilla-La Mancha and the Centro Nacional de Investigaciones Metalúrgicas in Madrid) [3]. They are low power (0.6 kW) and do not involve high construction and maintenance costs. It follows that the integration of solar ovens in a regular manufacturing process, located in industrial enterprises, usually built in populated centers, in areas with a temperate climate, solar furnaces have a major disadvantage in terms of energy availability to the user over time and location.

4.3. Costs

The cost of solar energy at source is zero, but for the use of any energy, the cost of investment and the costs of operation and maintenance of facilities are also important, correlated with the possibilities of recovering expenses. In the case of solar ovens, the investment costs depend to a large extent on the type and power of the installations. As it can be seen from figures 1-3, lens installations are simple and less expensive. The lenses receive energy directly from the sun and do not use heliostats and attenuators. The lenses are small in size and the sun tracking system is simple. The diameter of the lenses is limited by the possibilities of execution. That's why lens ovens have low power. The diameter of the spot in the focal plane is very small (0.5-1 cm) and as a result, the dimensions of the parts that can be heated quickly and evenly are reduced. High power solar ovens are very expensive. They use heliostats and concentrators with mirrors, which have very large total areas (e.g. heliostats have almost 3000 m2 and concentrators about 2000 m^2).The concentrators are fixed on buildings with 8-11 floors, and the work room where the focal plane is, is built in technological towers with 5-6 floors. The construction of concentrators and heliostats requires very large investments. In such ovens, the diameter of the spot in the focal plane is of the order of 20 - 40 cm, allowing the heating of larger parts or quantities of materials. The service life of the mirrors is about 30 years. This is in favour of investment recovery opportunities. Operating costs are relatively low. They are determined by the construction of devices necessary for the use of controlled atmospheres, cooling systems and devices for supporting, fixing and possibly moving the parts during processing. The operation does not require a large number of staff. Instead, maintenance costs can be very high. They depend on the type and size of the installations. The maintenance of solar furnaces consists primarily in wiping the surface of the lenses and mirrors. They are exposed to dust and airborne deposits or may be soiled by birds and insects and nebulae. The frequency of dusting depends on weather conditions, pollution, and fauna. Lens furnaces are easy to maintain and are small and ground. The lenses are made of acrylic, rigid vinyl and polycarbonate. They have a long service life. The maintenance of mirror furnaces is much more demanding and expensive due to their size and positioning. Mirrors are wiped off by washing with water or aqueous acid solutions (which may be polluting).

Solar furnaces do not have moving parts under construction, which are prone to wear and tear during operation. Elements that perform movement are heliostats that track the movement of the sun in the sky. However, they perform small and rare movements and are not subjected to high mechanical stress.

4.4. Environmental impact

Another advantage of solar ovens is the low negative impact on the environment. In some areas (desert areas) they can even have a positive impact, because by capturing the sun's rays by heliostats, soil degradation is prevented. The negative impact on the environment is also reduced due to the fact that no greenhouse gas emissions or waste are produced by combustion. However, some adverse effects on the environment may be reported. High consumption of acidic solutions used for washing and cooling mirrors can create environmental problems because they are difficult to neutralize. Decommissioning of mirrors is also a problem, as they contain environmentally harmful substances whose neutralization is not possible.

Another negative effect on the environment can be recorded on wildlife. Insects can be attracted to bright light and killed. Birds that hunt them can be killed by burning if they fly in the concentrator area. This can also affect predators that hunt birds. US federal officials have called the towers of the Californian desert solar-electric power plant "Ivanpah" "wild mega traps". According to reports, more than 133 birds were killed in their area in six months. Concentrated solar ovens for processing materials from Font Romeu, Parkent and Almeria present a similar danger, but have the advantage that being located in mountainous areas at high altitude (approx. 1100-1300 m) the fauna is reduced.

4.5. Total power and specific power in the focal plane

In recent decades, surface processing techniques have been developed for materials based on high-density energy beams (laser, plasma, electron beam, electric arc). Applied to the surface of the materials, they allow the creation of unbalanced microstructures with special properties, which cannot be obtained in conventional furnaces. Despite the effects on the properties, these techniques have a low energy efficiency, and the effect and location of the results on the surface of the parts are not uniform, because the particle beam section is very small. Therefore, it is necessary to scan the beams on the surface of the parts. In addition, it is not possible to adjust the intensity of the particle beams during processing. As a result, the only parameter through which the heating can be adjusted is the scan speed. Concentrated solar furnaces can offer some better opportunities for processing materials at very high temperatures, both technically and economically, although the power density obtained by laser is three to four times higher than that obtained by solar installations. This is because the total power of solar furnaces is much higher. As a result, larger areas and even bulk materials can be processed by using concentrated solar energy. Comparable or better effects can be obtained compared to particle beams.

Figure 4 shows the distribution of the solar energy amplification factor, at various distances "z", from the focal plane, in a lens furnace.

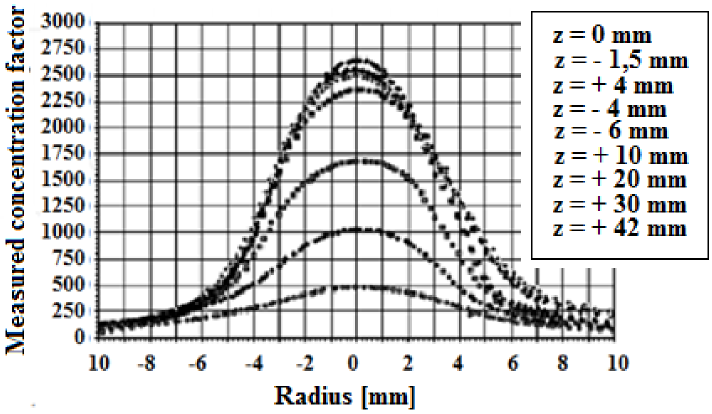

Fig. 4. Distribution of the solar energy concentration factor according to the distance "z" from the focal plane, lens furnace [3]

Figure 5 shows the specific power distribution in the focal plane, in the case of a vertical furnace with mirrors with a power of 5 kW. Temperatures of up to 3000-3500 °C can be reached on the surface of the parts to be processed in a few seconds. It is also possible to obtain volume heating (up to temperatures of 1300-1400 °C) achievable in conventional laboratory installations) reducing the heating time by 2-3 times compared to conventional installations. The use of concentrated solar energy can considerably reduce the cost of high temperature experiments and processing for unique small and even medium-sized parts. Combined with the wider range of surface changes that can be made on solar installations, there are other advantages to using this energy source. Thus, solar furnaces allow easy, prompt and precise modification of the spot power and therefore of the working parameters within wide limits. That is why they are particularly good tools for research and for acquiring scientific knowledge on the mechanisms involved in the processes generated at high temperatures.

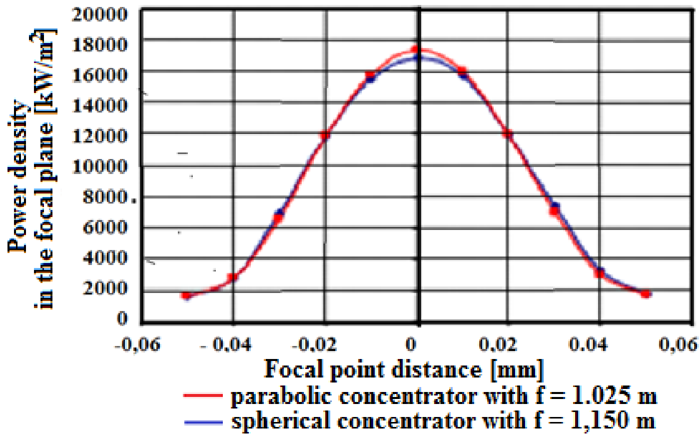

Fig. 5. Distribution of specific power in the focal plane, depending on the radius, vertical furnace with spherical and parabolic concentrating mirror [2]

4.6. Part surface processing

A disadvantage of heating in solar furnaces is the transmission of heat to the part through a single surface, which must be positioned in the focal plane, perpendicular to the axis of the spot. This disadvantage is specific to particle beam heating processes. In this case, the heat is transmitted inside the parts, mostly unidirectional. As a result, the temperature is markedly uneven in the case of thick parts. That is why heating in solar furnaces is recommended primarily for surface processing. Such processing is hardening of the surface of steel and cast iron parts, hardening by melting the surface of nodular cast iron parts, plating or alloying surfaces with thin layers, deposition of nanofilms. The high density of energy incident on the surface of the parts, allows the heating of the surface layer with very high speed and at high temperatures, necessary for these processes. Reaching temperatures of the order of 3000-3500 °C is possible in a few seconds. The thickness and temperature of the heated layer can be adjusted by adjusting the spot power and the heating time. The parts can be heated in tight spaces, in a protective atmosphere. Rapid cooling for hardening can be easily achieved by immersion in cooling tanks (placed under the work table), by spraying gas + liquid mixtures (air + water) or by insufflating gases (as needed). Processing is caused by the limitation of the size of the heated surfaces and the position of the focal plane of the installation (respectively the position of the heated surface). In low-power solar ovens can be heated quickly and relatively evenly surfaces with a diameter of 10-15 mm, while in very large furnaces with a diameter of 20-40 cm [4-8].

In order to process larger surfaces, it is necessary to scan the spot on the surface to be processed, by translating the part under the spot with a well-determined speed. This method of heating is specific to particle beam processing. Experimental research has shown that even in this case, often, the results are not uniform [13]. In addition, devices are required to control the movement of the parts. Scanning can be applied especially in the case of rectangular surfaces that have a width equal to the diameter of the spot and a large length.

Surface processing that does not involve melting materials (surface hardening) can be performed in both horizontal and vertical kilns. Instead, surface processing involving the melting of the surface state or the use of powders (surface hardening of nodular cast irons by melting or plating of surfaces by melting powders) can only be performed in vertical furnaces. This is so that the processed surfaces are positioned horizontally and the liquid material or powders do not flow.

However, experimental research has shown that even in the case of surface hardening of large surfaces, when the surface is heated by scanning and must be cooled in water or oil, there are problems related to the uniformity of properties on the processed surface. This is especially the case for vertical furnaces, when the surface to be processed is positioned horizontally in the focal plane [13]. In such cases it is not possible to cool the heated surface (by scanning the water jet), simultaneously with the heating, because the water flows towards the spot area, as shown in figure 6.

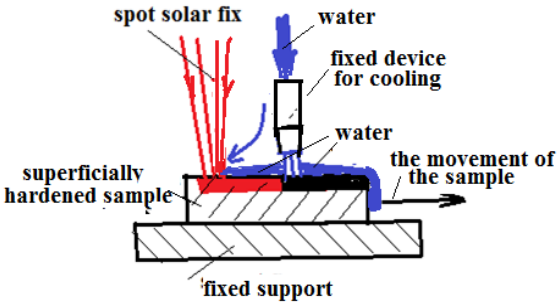

Fig. 6. Simultaneous heating and cooling by scanning the work part surface in a horizontal position, in a vertical solar furnace (incorrect processing)

If the processed surface is positioned horizontally, cooling must be performed by immersion in water or spray) only after the scan is completed, as shown in figure 7. And in this case at the time of cooling, the temperature is not uniform over the length and thickness of the part (due to different holding times along the length). The longer the maintenance time and therefore the temperature, the greater the length of the scanned surface.

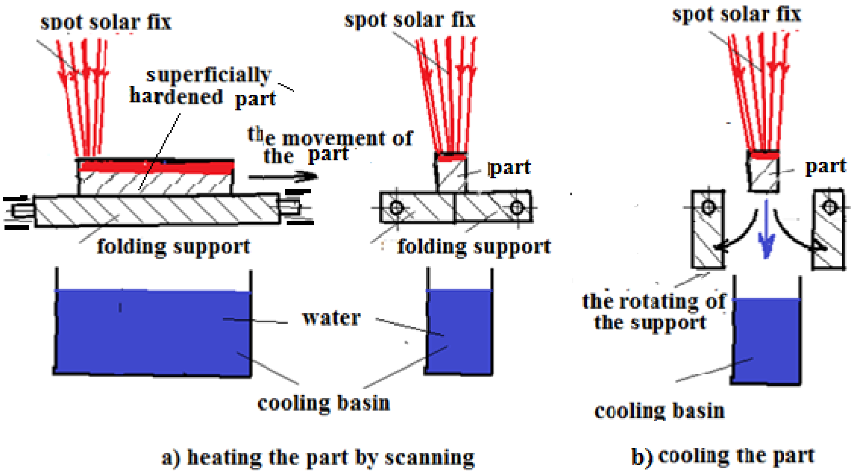

Fig. 7. Heating the surface of the parts by scanning and cooling by falling in the cooling basin, in a vertical solar furnace

In order to obtain uniform results on long surfaces, it is necessary that the cooling for surface hardening is also done by scanning the water jet on the surface of the part, simultaneously with the heating. For this, in the case of vertical furnaces, the surfaces to be heated and surface hardened by scanning must be positioned and moved obliquely, as shown in figure 8. In the case of horizontal furnaces cooling simultaneously with scanning, heating is possible because the surface of the part is positioned vertically. The parts move from top to bottom, and water cannot flow to the spot area, as shown in figure 9.

In the case of processing involving melting of the surface layer of parts or layers of powder applied to the surface of the parts (hardening of the surface of nodular cast iron by melting or plating and surface alloying of alloys by powder layers) the processed surfaces must be positioned horizontally (in vertical furnaces) so that the molten alloy or powders do not flow [1, 3]. In the case of large surfaces, these processes can be performed by scanning, because the cooling of the processed surfaces is done in the air. There is no danger of coolant leaking into the spot area. Such processing is not possible in horizontal furnaces.

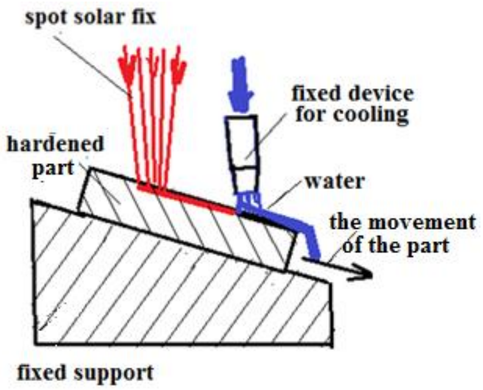

Fig. 8. Simultaneous heating and cooling by scanning the surface of the part in a vertical solar furnace (position and oblique displacement of the treated surface)

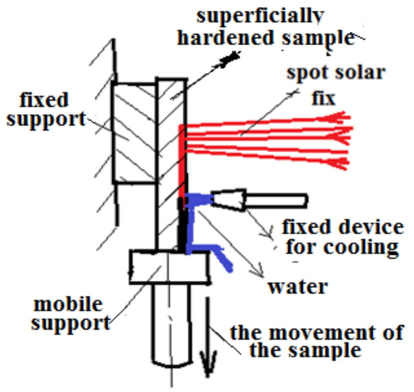

Fig. 9. Simultaneous heating and cooling by scanning the surface of the part in a horizontal solar furnace (position and vertical movement of the treated surface)

Another category of surface treatments of metal parts for which processing with concentrated solar energy has been experienced are thermochemical treatments. They aim to improve the properties of the surface layer by enriching it in various alloying elements, followed by a corresponding cooling. One of the thermochemical treatments commonly applied in industry, which has been tested in solar furnaces, is the nitriding of titanium and steel parts [3, 9-11]. It consists in heating and maintaining the parts at high temperatures (above 1000 °C) in gaseous or liquid media, which by dissociation release nitrogen atoms. During maintenance, nitrogen atoms are adsorbed through the surface of the parts and diffuse into the crystal lattice, forming solid solutions with a high nitrogen content and hard chemical compounds. Subsequent cooling is used to obtain nonequilibium structures with the desired properties. In the case of titanium-based alloys, experiments were performed on nitriding by heating with solar energy, in a gaseous atmosphere, of the Ti6Al4V alloy, with an initial hardness of 400HK [3]. The Ti6Al4V samples were placed in a reaction chamber (box) into which the controlled nitrogen atmosphere was introduced. The cover of the reaction chamber must be fitted with a quartz window to allow the incidence of solar energy on the surface of the part. Experiments were performed in the Fresnel lens furnace and in the vertical mirror furnace. At the end of maintenance it is possible to cool quickly (if necessary to obtain unbalanced microstructures). For thermochemical treatments, the solar energy concentrated on the surface of the part has a great advantage, because it also has a strong effect of activating the adsorption and diffusion of nitrogen atoms in the base material. As a result, the duration of the nitriding process is greatly reduced. The experiments consisted in heating to temperatures between 1000 °C and 1200 °C with maintenance times between 5 and 30 minutes. These led to results comparable and even superior to those obtained in electric furnaces at treatment cycles of several hours. By maintaining for 15 minutes at 1200 ºC on the surface, a layer with a thickness of 400 µm, Ti_2N nitride, with very high hardness, 2600 HK was formed, and the wear rate decreased 2 times [3]. A disadvantage of applying thermochemical treatments in a gaseous atmosphere in solar furnaces is that the size of the processed surfaces is limited by the diameter of the spot. The surface of the parts must be heated directly by the incidence of the rays, as the thermochemical treatments are not suitable for heating by scanning.

In the case of non-alloy steels, nitriding treatments were performed by heating with solar energy in a salt bath. A technology has been pursued that combines the use of non-polluting salts with the activating effect of concentrated solar energy [3]. The possibility of substituting highly contaminating cyanide salts (used for liquid nitriding in electric furnaces) with less toxic KNO_3 salt has been studied. The nitriding of two types of steel was studied: a low-alloy low-carbon steel (AISI 1042) and a high-alloy high-speed tool steel (M2). The results were compared with those obtained using an electric muffle furnace. The treatment in solar furnaces resulted in the hardening of the surface of the two steels by the interstitial diffusion of nitrogen in the iron network. In addition, a very hard nitride layer was formed in the M2 samples. Due to the activating effect of the process, produced by concentrated solar energy, the treatment time was greatly reduced. In the case of AISI1042 steel in the solar oven, the time was 35 minutes, compared to the 90 minutes required in an electric muffle furnace. In the case of the M2 sample, the reduction of the treatment time using concentrated solar energy is more significant. In the Fresnel lens furnace, the time was 60 min, in the vertical PSA furnace it was 15 min, and in the muffle electric furnace the time is 180 min.

Thermochemical treatments have the same limitations related to the possibility of implementing solar furnaces (medium and high power) on industrial platforms, as a result of construction costs, but also of continuity in operation. In the case of lens furnaces, the disadvantages are also related to the low power and the small diameter of the spot.

4.7. Surface processing for obtaining nanostructures

A special type of solar processing based on heating the surface of materials is to obtain molecules and nanostructures. They use the phenomenon of vaporization to develop special microstructures by controlling vapour cooling [1, 3]. Vapours are produced by vaporizing or sublimating the surface of samples heated by concentrated sunlight. They then cool in a gaseous phase (called a buffer) and can be deposited on a solid target material. The decrease in vapour temperature results in the formation of clusters of molecules or nanoparticles. If the interaction between the buffer gas and the vapours is very low, the atoms and molecules in the gas phase can be collected on the surface of a target part. The characteristics of the deposition depend on the pressure, composition and flow of the buffer gas and the geometry of the reactor. Through this process of vaporization - condensation can be obtained different types of nanoparticles (molecules, nanoparticles, nanolayers), Quality and properties of the product, are a complex function of pressure, gas composition and flow temperature evolution containing vapours and particles. By heating in solar ovens, nanophases were produced based on carbon, but also based on other elements, zirconium, cerium, zinc, etc. These materials can have special properties (magnetic, electrical, photocatalytic).

4.8. Processing of materials in volume

Compared to particle beams, solar furnaces have the advantage that they can perform heating and volume processing. They can be processed by melting, bulk powder materials or by sintering. This is due to the total power and the larger surface area of the spot.

In the case of melt processing, powders or bulk materials must be placed in rotating crucibles. They can be heated directly (by the incidence of the spot on the surface of the material) or indirectly (by heating the lid or the wall of the crucible). The rotation of the crucible is necessary for the uniformity of the temperature and the melting, through the circulation of the liquid material inside the crucible, due to the centrifugal forces. Crucibles can work batch wise or continuously.

Bulk material processing is applied for the purification of refractory oxides with high melting temperature or for obtaining refractory shaped products. On the solar platform from Font-Romeu were made several installations with rotating crucible for various processing of materials by bulk melting [1]. They include devices for rotating, cooling and thermal insulation, for sealing work chambers, depressurizing and introducing protective atmospheres, for supplying reactants or removing the resulting gases and waste, and for disposing of the final product. SiO_2 crucibles and other ceramic products were obtained. The purification of materials is based on the melting of materials in a controlled atmosphere and the removal of impurities by evaporation in the form of gases.

Sintered processing of compacted powders by pressing also requires heating in the entire volume of the parts. In this case, in order to avoid overheating of the surface of the products, indirect heating is applied [1, 3, 12, 14]. The parts compacted by pressing are placed in refractory boxes. The solar spot heats the lid of the box, and it heats the product subjected to sintering by radiation. This type of heating is similar to sintering in muffle electric ovens. However, it has the disadvantage that the bottom of the box remains cold being covered by the part subjected to sintering. As a result, the temperature gradient on the thickness of the part is relatively large. That is why the properties of products sintered in solar ovens can be uneven in thickness. Research applied in laboratory conditions has shown that in the case of sintering in solar furnaces samples of AlSi12 + 5% SiC, with a thickness of 6 mm at 500-550 °C, the temperature difference between the upper and lower surface of the part may have values between

50-130 °C [14]. The higher the temperature compaction pressure, the greater the temperature difference. Instead, sintering in solar furnaces has the advantage that the process time (heating + maintenance) is less than 2-3 times, compared to sintering in electric laboratory furnaces [3, 14]. The reduction of the sintering cycle duration is determined by the faster heating in the solar furnace, in relation to the heating time of the electric furnace. However, sintering in solar furnaces has low productivity. The dimensions of the sintering boxes are small, being limited by the diameter of the spot. Often a single piece is sintered in a box. In electric furnaces, many more parts can be sintered simultaneously, because the dimensions of the working chamber are much larger. In addition to these furnaces the side walls and even the bottom of the furnace are warm, ensuring a more uniform sintering of the parts. Thus, even if the sintering time of the parts with concentrated solar energy is shorter, the applicability in industrial regime is not efficient, because the productivity and the uniformity of the properties are important indicators.

4.9. Intensification of microstructural transformations under the effect of photonic impact

Another advantage of processing in solar furnaces is the stimulation and intensification of microstructural transformations caused by the impact of photons on the surface of materials. This aspect is especially important in the case of thermochemical treatments. The dense impact of photons on the surface of materials, achieves an intense and direct energy transfer on the atoms in the structure. Transformations may occur which, under heating conditions in conventional installations, do not take place. It is possible to decompose chemical compounds with high stability, advanced dissolution of elements in the crystal lattice, obtaining supersaturated solutions or on the contrary the formation of interatomic compounds with high dispersion or compounds and mixtures between elements considered incompatible. Such structures give the materials some high use properties compared to the properties obtained by processing in conventional furnaces. For example, resistance to corrosion, wear, refractoriness, structural and dimensional stability to temperature variations, properties necessary for products working under special conditions, in the chemical industry, in biomedicine, in aeronautics, in the atomic and nuclear industry, etc. [8, 15, 16].

4.10. Establishing working conditions

Worldwide, the number of solar installations with concentrated energy is small. Existing installations have very different characteristics (total power, spot diameter, amplification factor and specific power in the focal plane, position of the focal plane). Because of this, for each solar furnace, the working conditions are different. As a result, for each furnace, the working parameters must be established for each type of processing and type of part size. It is necessary to establish the position of the part, the specific power required in the focal plane, the opening of the attenuator, the duration of the heating-maintenance cycle, the scanning speed (if applicable), the cooling mode, the protective atmosphere, etc. Establishing the working parameters requires a large number of experiments, for each type of part size. This involves a lot of time, experimental measurements of the working parameters and of the obtained properties, consumption of materials and labour.

It is possible to perform a predetermination of the working conditions required for thermal processing in solar furnaces by computer simulation of heating in such furnaces [17, 18]. In research and industry, software is used to simulate the heating and cooling of thermally processed parts, in order to design and optimize work technologies. Such software, adapted to the particularities of solar furnaces, can also be used to simulate solar heating. With their help, the evolution of the temperature field in the parts subjected to heating can be determined over time. Thus, the recommended working regimes for various processing can be preset. For this purpose, it is necessary to know as accurately as possible the specific power distribution in the focal plane, the thermophysical characteristics of the materials and the adsorption coefficient of solar energy on the incident surface. In order to obtain correct results, it is necessary that the software be previously validated through experimental verifications. Simulation research can significantly reduce experimental research. Such software was developed and validated at the Transilvania University of Brașov [17, 18]. It allows the establishment of recommended work cycles for surface heat treatments, but also studies on obtaining volume heating.

4.11. Reproducibility of working conditions

Another problem related to the use of solar furnaces is to ensure the reproducibility over time of working conditions and therefore the results of material processing. The reproducibility of the working conditions is all the more necessary as the power density and the heating speed on the surface of the parts are higher. Under these conditions, deviations of the specific power in the focal plane or of the processing time can have important effects on the results. The specific power in the focal plane is determined by the specific power of the direct solar radiation on the earth and by the opening of the attenuator flaps. Direct solar power on earth is very changeable. It changes from day to day and even from hour to hour, depending on weather conditions, the position of the sun in the sky. For this reason, medium and high power solar ovens have solar flux dampers, placed between the heliostat and the concentrator. They can promptly adjust the intensity of the radiation in the focal plane. Changes can be made even during processing. This can ensure the parameters and working conditions necessary for various processes, but also the reproducibility of work cycles. However, it is necessary for each solar oven to have a detailed database, which correlates the specific direct solar power on the ground, with the opening of the attenuator flaps and with the power density in the focal plane. The adjustment of the attenuator, respectively of the working conditions, can be done manually or automatically. This requires the continuous measurement of direct solar radiation on the ground and the coupling of the measuring installations with programming systems and automatic control of the attenuator adjustment.

5. Conclusions

Concentrated solar energy furnaces have peculiarities, which involve opportunities for processing and testing materials, but also significant limitations. Opportunities are applicable for numerous processes. In some cases, the working conditions and results are better than those obtained in conventional furnaces or other types of heating installations.

The limits are related to:

- the dependence of the seasonal operation, on the atmospheric conditions on the day-night succession and on the latitude;
- high investment costs and very large, occupied areas, in the case of high power furnaces;
- the dimensions, geometry and positioning of the surfaces that are heated.

These limitations make it difficult to integrate such furnaces into industry in series production in enterprises. Therefore, solar furnaces are primarily recommended for processing single or small parts, to be carried out in research centers on solar platforms, based on collaborations between beneficiaries and executors. It is especially suitable for processing that requires high temperatures and heating rates (purification of materials, parts and components of refractory materials, surface treatments) or for obtaining microstructures with special properties. It is necessary to know very well the conditions of processing and adjustment of facilities based on a prior research.

A very important and even irreplaceable field of applicability is the testing of the properties and behaviour of materials at high temperatures. Solar furnaces offer the advantage that the working parameters can be adjusted within wide limits, and the tests can be performed in tight working rooms and can combine solar heating with other surface protections (vacuum, UV radiation, ion bombardment). The tests study in particular the mechanisms of degradation of materials, the properties and chemistry of surfaces, dimensional stability, emissivity at high temperatures, diffusion, or recombination of atoms. They are especially needed for high-level areas of activity (chemical, aerospace, nuclear, etc.).

References

1. Flamant G., Balat-Pichelin M. (2009): *Elaboration and Testing of Materials Using Concentrated Solar Energy*, in Blanco G., Malato S.: *Solar Energy Conversion and Photoenergy Systems*. Vol. I, EOLSS, ISBN 978-1-84826-285-0
2. Rodríguez J., Cañadas I., Zarza E. (2014): *PSA vertical axis solar furnace SF5*. Energy Procedia, ISSN 1876-6102, Vol. 49, pp. 1511-1522, https://doi.org/10.1016/j.egypro.2014.03.160
3. Herranz G., Rodríguez G.P. (2010): *Uses of Concentrated Solar Energy in Materials Science*, in Rugescu R. (editor): *Solar Energy*, p. 145-172, InTech, ISBN 978-953-307-052-0, http://www.intechopen.com/books/solar-energy

4. Yu Z.-K., Zong Q.-Y., Tam Z.-T. (1982): *A preliminary investigation of surface hardening of steel and iron by solar energy*. Journal of Heat Treating, ISSN 0190-9177, Vol. 2, is. 4, pp. 344-350
5. Yu Z.-K., Zong Q.-Y., Tam Z.-T. (1983): *A further investigation of surface hardening of iron and steel by solar energy*. Journal of Heat Treating, ISSN 0190-9177, Vol. 3, is. 2, pp. 120-125
6. Vázquez A.J., Damborenea J.J. (1990): *Aplicaciones de la energía solar al tratamiento de materiales metálicos. Resultados preliminares.* Revista de Metalurgia, ISSN 0034-8570, Vol. 26, no. 3, pp.157-163
7. Rodríguez G.P., López V., Damborenea J.J., Vázquez A.J. (1995): *Surface transformation hardening on steels treated with solar energy in central tower and heliostat field*. Solar Energy Materials and Solar Cells, ISSN 0927-0248, Vol. 37, is. 1, pp. 1-12, https://doi.org/10.1016/0927-0248(94)00169-S
8. Rodríguez G.P., Damborenea J.J., Vázquez A.J. (1997): *Surface Hardening of Steel in a Solar Furnace*. Surface and Coatings Technology, ISSN 0257-8972, Vol. 92, is. 3, p. 165-170, https://doi.org/10.1016/S0257-8972(97)00073-X
9. Shen Y.Z., Oh K.H., Lee D.N. (2006): *Nitriding of Interstitial Free Steel in Potassium – Nitrate Salt Bath*. ISIJ International, ISSN 0915-1559, Vol. 46, is. 1, pp. 111-120, DOI:10.2355/isijinternational.46.111
10. Shen Y.Z., Oh K.H., Lee D.N. (2006), *Nitrogen strengthening of interstitial-free steel by nitriding in potassium nitrate salt bath*. Materials Science and Engineering: A, ISSN 0921-5093, Vol. 434, is. 1-2, pp. 314–318, https://doi.org/10.1016/j.msea.2006.06.127
11. Herranz G., Rodriguez G. (2007): *Surface Nitriding of M2 HSS using Nitrate Salt Bath*. Proceedings of Euro PM2007, Vol. 3, pp. 425-428, ISBN 978-1-899072-30-9
12. Almeida Costa Oliveira F., Shohoji N., Cruz Fernandes J., Guerra Rosa L. (2005): *Solar sintering of cordierite-based ceramics at low temperatures*. Solar Energy, ISSN 0038-092X, Vol. 78, is. 3, pp. 351-361, https://doi.org/10.1016/j.solener.2004.08.013
13. Stoicanescu M., Crisan A. ,Milosan I., Pop M.A., Rodriguez G.J., Giacomelli I., Bedo T., Canadas I. M., Semenescu A., Florea B., Chivu O.R. (2019): *Heat Treatment of Steel 1.1730 with Concentrated Solar Energy*. Materiale Plastice, ISSN 2668-8220, Vol. 56, no. 1, pp. 262-270, http://www.revmaterialeplastice.ro/pdf/52 STOICANESCU 1 19.pdf
14. Milosan I., Varga B., Bedo T., Pop M.A., Balat-Pichelin M., Luca-Motoc D., Stoicanescu M. (2019): *Thermal processing and thermal analysis of AlSi12–SiC hybrid composites sintered*. Journal of Thermal Analysis and Calorimetry, e-ISSN 1588-2926, Vol. 138, pp. 2937-2944, https://doi.org/10.1007/s10973-019-08567-0
15. Milosan I., Florescu M., Cristea D., Voiculescu I., Pop M.A., Cañadas I., Rodriguez J.,Bogatu C.A., Bedo T. (2020): *Evaluation of Heat-Treated AISI 316 Stainless Steel in Solar Furnaces to be used as Possible Implant Material*. Materials, ISSN 1996-1944, Vol. 13, no. 3, 581, https://doi.org/10.3390/ma13030581
16. Milosan I. Cristea D., Voiculescu I., Pop M.A., Balat-Pichelin M., Predescu A.M., Bogatu C.A., Bedo T., Berbecaru A.C., Geantă V., Gabor C., Isac L.A., Sarbu F.A., Oancea G. (2019): *Characterisation of EN 1.4136 stainless steel heat-treated in solar furnace*. International Journal of Advanced Manufacturing Technology, ISSN 0268-3768, Vol. 101, is. 9-12, pp. 2955-2964, https://doi.org/10.1007/s00170-018-3153-9
17. Stoicănescu M., Crișan A., Pop M.A., Ciobanu I. (2018): *Experimental Verification of a Software for Simulation of Heating Metallic Parts in Solar Furnaces*. RECENT, ISSN 1582-0246, Vol. 19, no. 2(55), p. 77-88, https://doi.org/10.31926/RECENT.2018.55.077
18. Ciobanu I., Stoicănescu M., Munteanu S.I., Monescu V. (2018): *Mathematical Model and Soft for the Heating Simulation of Metallic Parts in Solar Furnaces*. RECENT, ISSN 1582-0246, Vol. 18, no. 1(54), 2018, pp. 19-36, https://doi.org/10.31926/RECENT.2018.54.019