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HEAT TREATMENT OF STEEL PRODUCTS AS AN EXAMPLE OF TRANSPORT PHENOMENON IN POROUS MEDIA

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The paper defines the concept of porous charge and presents its general classification. The mechanisms of heat transfer that take place in this type of charge during heat treatment as an example of transport phenomenon were discussed. The main thermal property of porous charge is the effective thermal conductivity k_{ef}, which corresponds to the thermal conductivity of homogeneous substances. Introduction of the concept of the effective thermal conductivity substantially facilitates analysis of complex heat flow processes connected with heat treatment of porous charge.

Keywords: steel porous charge, complex heat transfer, heat treatment, effective thermal conductivity

INTRODUCTION

The transport phenomenon in different porous media has attracted the attention of scientist and engineers due to its many technical and practical applications. One of the example of such phenomena are processes of heat transfer. Areas and applications where the study of heat transfer in porous media becomes mandatory are: extraction of geothermal energy, soar pounds, food preservation, building environment, microstructure electronics, global warming, power pants, gas-cooled nuclear reactors, catalytic reactors and high performance cryogenic insulations [1].

Due to their structure, porous media are categorized into two basic groups [2]: intergranular-intragranular and fractured, whereas in terms of the form of the solid phase they are divided into cellular (solid phase is continuous) and granular materials (solid phase is discrete) [3].

In industrial practice exists another one area where take place heat transfer processes in porous media. It relates to the heat treatment of steel porous charge. These types of charge are two-phase structures consisting of a metal skeleton of the solid phase and the voids which are filled with gas. Presented paper involved general characterization and classification of porous charge and discussion of the phenomena that determine its heating and cooling processes.

STEEL POROUS CHARGE

Porous charge is considered as products submitted to heat treatments which are characterized by presence of empty spaces (pores) in its volume. These spaces are filled with the fluid medium creating the atmosphere of the furnace in which heat treatment is performed. In general, there are three types of porous charge: coils, bundles and piece charge. In coils are heated sheets, tapes, wires and blank. Two typical examples of this charge, sheet and wire coils are presented in Figure 1. The second groups are bundles of long products. This kind of charge can be further divided into two subcate-

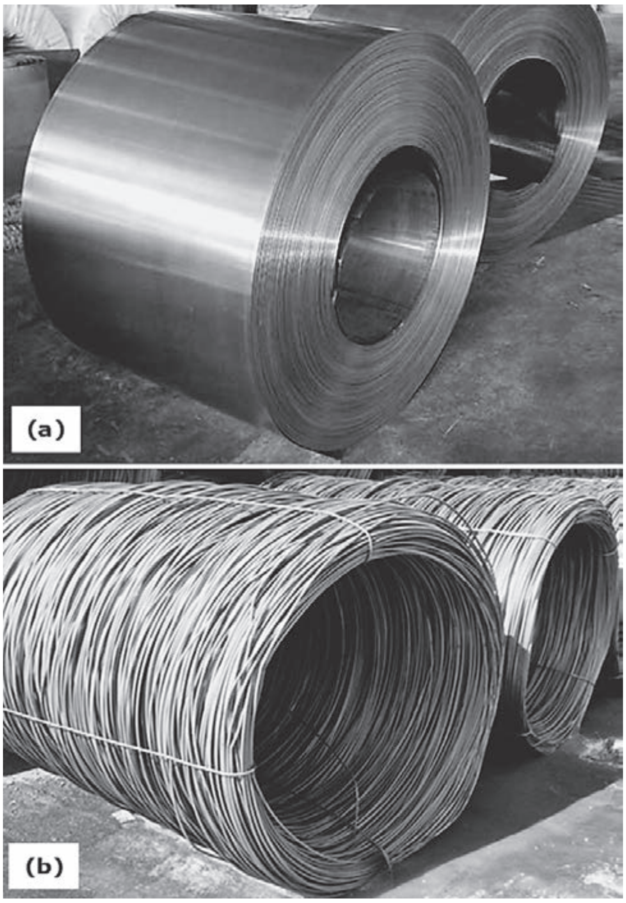

Figure 1 Examples of porous charge in the form of coils: a) sheet, b) wire

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gories: charge with external porosity or with mixed porosity. The first group is bundles of various types of bars (Figure 2). The charge with mixed porosity is composed of hollow components, such as pipes or rectangular sections (Figure 3).

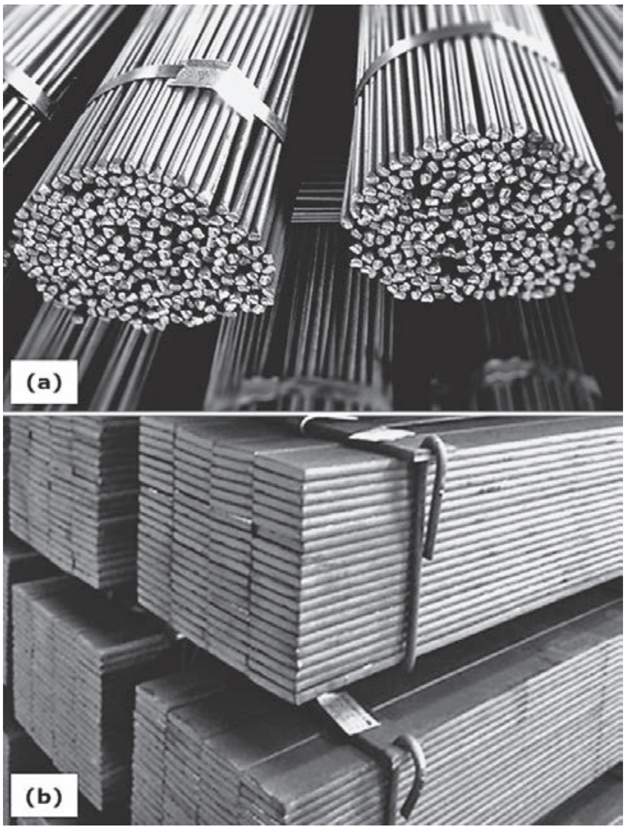

Figure 2 Bundles with external porosity:
a) round bars, b) flat bars

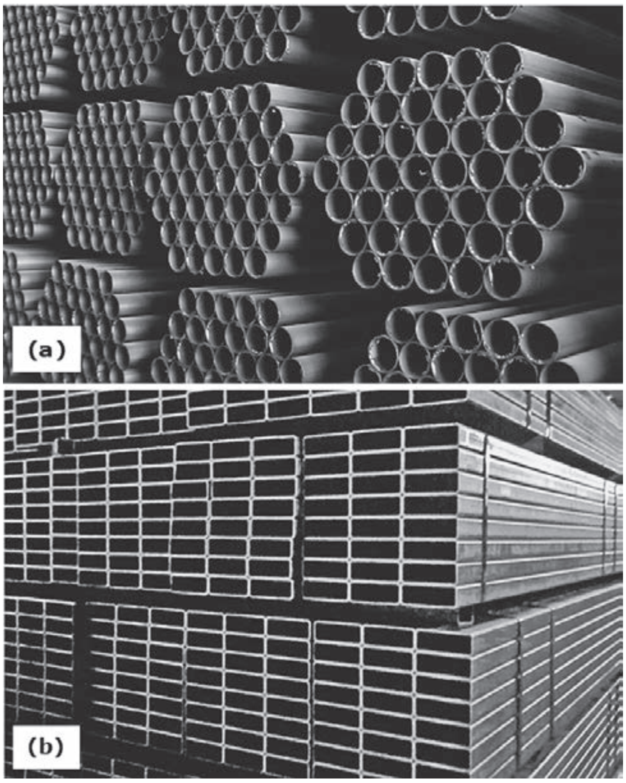

Figure 3 Bundles with mixed porosity:
a) round pipes, b) rectangular sections

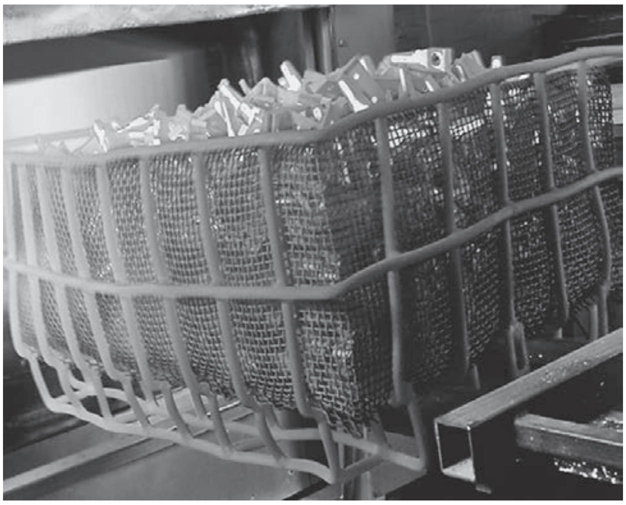

Figure 4 Porous charge in the piece form

The third category of the porous charge is also termed piece charge and is represented by small products (bolts, nuts, pins, pivots or parts of bearings) heated together in special containers or baskets. Example of this charge is illustrated in Figure 4.

The basis physical feature of discussed charge is porosity φ. The lowest porosity is observed for the sheet coils, which represent the system of many adjacent thin layers of metal and gaps. The width of these gaps depends on the force used during coil winding and ranges from 10 to 100 μm [4]. The porosity of such a charge ranges from 0,5 to 7 %. Much greater porosity show wire coils, which depends on the density of coils winding. Wire coil wound with maximal packing has a porosity of 25 %, whereas the porosity of the coil wound loosely may ever reach the porosity of 70 %.

A much varied porosity is observed for bundles, which is determined by the type of products. Bar bundles are characterized by porosity ranging from 2 to 30 %. The lowest values concern bars with rectangular cross-sections. With maximal packing of such bundles, the parameter φ for such a charge is from 2 to 5 %. In practice, however, it is difficult to perfectly arrange the bars in the bundle and the real porosity of the charge should be adopted as ranging from 10 to 25 %.

Round bar bundles with maximal packing have the porosity of 9,1%. However, similar to rectangular bars, porosity of bundles of round bars is higher. The highest porosity is found in the bundles of hollow products. In this type of charge, there is external porosity, concerned with presence of spaces between components like in the bar bundles, and internal porosity, connected with presence of empty spaces in their interior. Total porosity of these types of charge for thin-walled products may even exceed 90 %. Porosity of piece charge is much varied. In this case, the parameter depends on the shapes of the products.

HEAT TREATMENT OF POROUS CHARGE

Heat treatment of steel products, including porous charge, is performed in a number of furnaces which are characterized by: the type and location of the heating space, character of operation, form of energy supplied, size and power. The coils are mainly processed in bell-type furnaces, where the heating process is performed in protected atmospheres. Wire coils are processed in nitrogen atmosphere, whereas sheet coils are processed in hydrogen [5, 6]. The example of such furnace is presented in Figure 5a. The sheet coils are also processed in Uniflow Annealing System Furnaces, where the atmosphere is provided by the mixture of 93 % of nitrogen and 7 % of hydrogen [7].

Furnaces used for bundle processing are much more varied. Mass production occurs in continuous furnaces [8, 9]. In production of lower scale, periodical furnaces are used such as: soaking, bell-type and chamber furnace. Due to the geometry of soaking and bell-type furnaces, the bundles are heated in vertical position in special baskets (Figure 5b). Piece charge is typically heated in the furnaces with periodical operation, using for the purpose the bell-type and chamber furnaces.

HEAT TRANSFER INSIDE THE POROUS CHARGE

The phenomenon of heat transfer inside the porous charge will be discussed on the example of the bundle of pipes. For simplification, it was assumed that heat flow is one-dimensional and occurs in the radial direction. This charge (see Figure 3a) is a periodical layered medium. Individual layers of pipes are separated with gaps and joints i.e. the areas where adjacent pipes are in contact. Therefore, the analysis of heat flow in this charge should take into consideration the flow that occurs in the area of the pipes and between layers. In all of these cases, this phenomenon is complex and represents a combination of several mechanisms of heat exchange. The basic mechanism of heat exchange that occurs in the area of pipes is heat conduction, which is observed mainly on the periphery of the walls and, less intensively, in the gas that fills the interior. Intensity of both phenomena is largely dependent on thermal conductivity for individual phases. Apart from conduction, free convection is also observed in gas, connected with action of mass forces resulting from the differences in density, which is caused by the difference in temperatures [10, 11]. The third method of heat transfer which takes place in the inside area of pipes is heat radiation. This type of heat exchange is connected with the consecutive processes of emission and absorption by the internal surfaces of pipes, accompanied by changes in their temperatures. The radiation intensity is determined by mean temperature of the walls and their radiation properties expressed mainly by the emissivity [12]. Furthermore, the heat flow between layers of pipes occurs through conduction, free convection in the gas and radiation between the external surfaces. In contrast, heat in the joints is transferred through contact conduction [13].

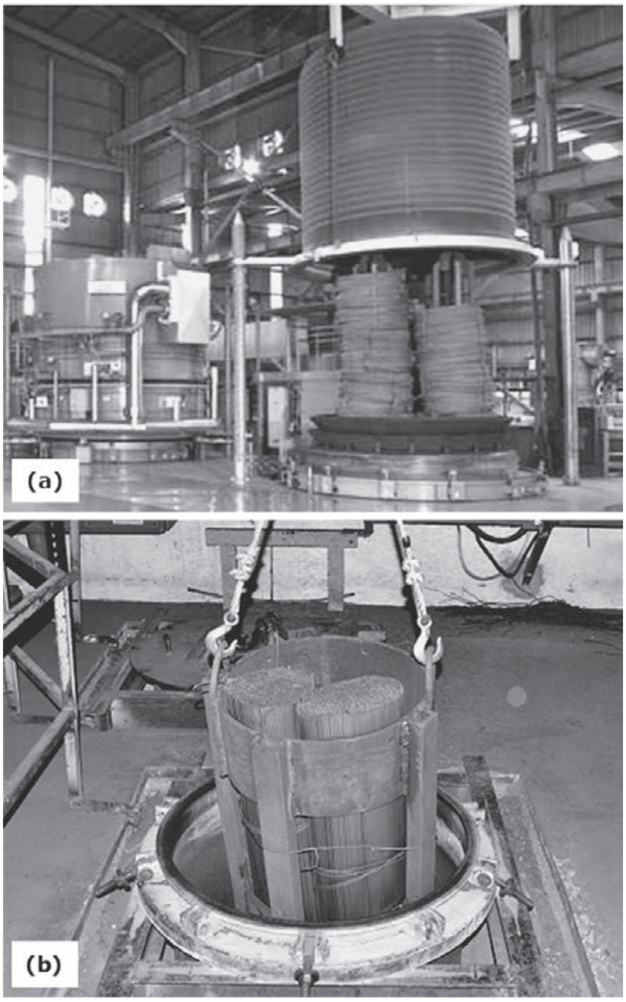

Figure 5 Examples of heat treatment of porous charge: a) wire coils heated in the bell-type furnace, b) bar bundles heated in the soaking furnace

In similar manner heat is transferred in other types of porous charge. This phenomenon is much less complex in the case of the charge with external porosity. In this case, the radiation, conduction and convection of gas do not occur inside the individual elements. However, other phenomena, such as conduction in the solid phase, conduction and convection in gas and thermal radiation between external surfaces of adjacent products and the contact conduction are observed.

Full mathematical description of the heat flow in the porous charge requires a number of complex relationships, which, in practice, is very burdensome. Therefore, the popular approach is to use the effective thermal conductivity k_{ef}, which corresponds to the thermal conductivity of homogeneous substances [1, 14]. Introduction of the concept of the effective thermal conductivity with respect to porous charge substantially facilitates analysis of complex heat flow processes connected with heat treatment.

CONCLUSIONS

Apart from quality, the operations of heat treatment also impact on the efficiency and energy consumption of production and emission of pollutants [8]. Therefore, these processes are being optimized. In modern production lines, this is ensured by automation systems that control the operation of furnaces based on the results of computations performed by means of complex mathematical models. These solutions have been successfully used in the metallurgical industry for over three decades [15-17]. Ensuring correctness of such models requires good knowledge of thermal properties of the heated charge. If heat treatment is used for monolithic steel components, evaluation of this parameter is not difficult. However, in the cases of porous charge, this property is effective thermal conductivity. For this reason, knowledge about the values of coefficient k_{ef} of the porous charge is of key importance from the standpoint of correct results of heating simulations.

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