LABORATORY 13 REPORT

Heat treatment technologies and devices

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Introduction:

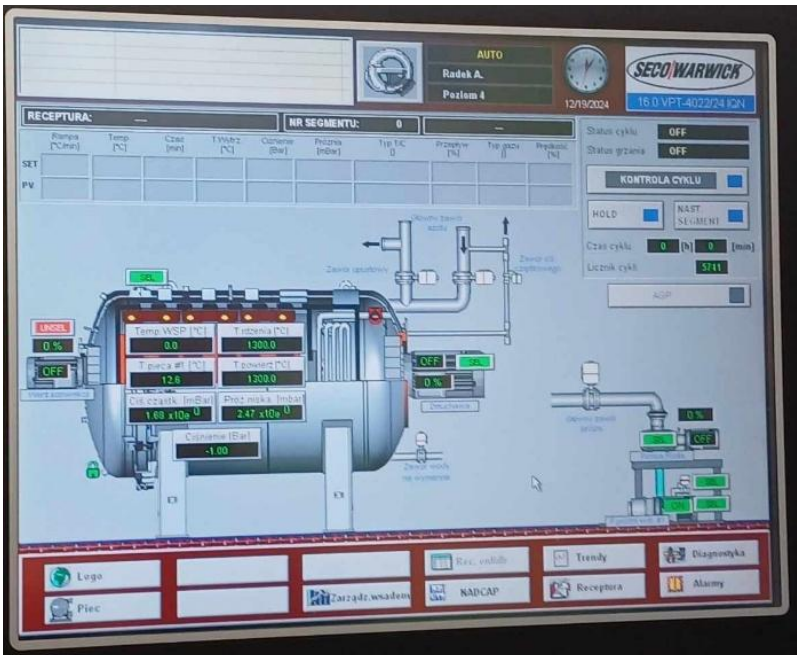
Heat treatment is essential in manufacturing, improving workpiece properties by altering its microstructure through controlled heating and cooling. Metals, especially steels, undergo processes like annealing or normalizing to minimize residual stresses by slow cooling from the austenitic state. In contrast, rapid quenching creates metastable structures, enhancing strength and hardness but introducing significant residual stresses. Techniques like nitriding, carburizing, and advanced production of High Strength Metallurgical Graphene will be discussed in this report.

Task 1: Describe the construction, principles of operation and control methods of vacuum carburizing equipment. Describe elements preparation. Use pictures taken or sketches made during laboratory.

Carburizing is a thermo-chemical process that hardens iron or steel by infusing carbon from a carbon-rich material at 850–1000°C. It is widely used to increase the hardness and wear resistance of low-carbon steel. Vacuum carburizing achieves this by heating under reduced pressure and introducing carburizing gases like acetylene or ethylene to interact with the material.

A VPT furnace is designed with a sealed, high-strength chamber capable of maintaining low pressure for vacuum operations. It features heating elements ensuring uniform heat distribution. The furnace includes a vacuum pump system to achieve the required pressure levels and a cooling mechanism, such as gas quenching or water jackets, to regulate temperature during processing. Insulation materials line the chamber to minimize heat loss, while control systems ensure precise temperature and pressure adjustments for consistent results.

VPT furnace



operator panel

VPT furnace indicators

The laboratory furnace showcased has a maximum heating temperature of 1300°C and supports pressures of up to 12 bar for nitrogen and 15 bar for hydrogen and helium. It operates with a 3 x 400V, 50 Hz power supply and has a power rating of 100 kVA. With a total weight of 5500 kg, the furnace can accommodate a maximum charge weight of 200 kg, loaded using a forklift. It handles workpieces up to a maximum size of 60 x 40 x 40 cm.

rating plate of VPT furnace

workpiece on forklift

The gas mixer and cleaning process play key roles in ensuring the efficiency and precision of the vacuum carburizing system. The gas mixer precisely combines and regulates the flow of gases, such as acetylene or ethylene, to maintain the optimal carburizing environment. Thorough cleaning of the workpiece using an ultrasonic cleaner, aided by solvents like alcohol or acetone, is essential to remove contaminants like oil and grease. This prevents impurities from interfering with the process.

Once cleaned, the workpiece is placed in the furnace chamber, which is sealed, and a vacuum is created by removing oxygen particles. This vacuum environment is critical to the carburizing process, which includes the following steps:

1. Element Heating: The workpiece is gradually heated to 900–1050°C for most steels or 1000–1200°C for high-speed steels used in tool production. Heating rates range from 2–10°C per minute, with the process typically lasting around 20 hours.

2. Carbon Introduction: Gases like acetylene or ethylene introduce atomic carbon, which diffuses into the steel surface. Solid carbon deposition is avoided to ensure uninterrupted diffusion.

3. Carbon Diffusion: Atomic carbon penetrates the surface and diffuses throughout the workpiece. These carburization and diffusion steps are repeated as needed to achieve the desired carbon profile.

Finally, the material undergoes quenching with pressurized nitrogen for rapid cooling, achieving the desired microstructure. Optionally, tempering follows to reduce internal stresses and enhance toughness.

<u>Task 2:</u> Describe the construction, principles of operation and control methods of low pressure nitriding equipment. Describe elements preparation. Use pictures taken or sketches made during laboratory.

Low-pressure nitriding equipment consists of a hermetically sealed retort chamber that isolates the workpiece from atmospheric conditions. The primary nitrogen source is ammonia (NH_3), which dissociates at temperatures above 450°C into nascent nitrogen and hydrogen. The active nitrogen atoms diffuse into the steel surface, forming nitrides that enhance hardness. This process operates at a temperature of approximately 550°C, ensuring compatibility with previously tempered steels.

nitriding furnace

The furnace includes two chambers: one for heating the workpiece and another for cooling it, ensuring continuous operation. A sulphur evaporator is an optional feature for further treatment, converting solid sulphur into vapor at around 160°C to enhance surface properties.

furnace chambers

nitriding workpiece charging basket

The nitriding atmosphere is carefully managed to maintain optimal thermodynamic conditions. Sensors monitor the dissociation of ammonia and the nitriding potential, allowing adjustments to achieve desired microstructures. These controls prevent deviations that could impair the formation of the diffusion zone or compound layer.

Before nitriding, steel components are tempered to stabilize their microstructure. The process involves:

1. Heating: The workpiece is heated to the desired temperature inside the retort.
2. Ammonia Dissociation: Ammonia decomposes into nitrogen and hydrogen, with nitrogen atoms diffusing into the steel surface.
3. Absorption and Nitriding: Nitrogen atoms form nitrides with alloying elements, improving wear resistance and durability.

Nitriding is widely used for components like gears, shafts, and cutting tools due to its ability to enhance surface hardness without causing significant distortion.

Task 3: Describe the construction, principles of operation and control methods of HSMG production unit. Use pictures taken or sketches made during laboratory.

The HSMG production unit is an advanced furnace designed for the production of High Strength Metallurgical Graphene (HSMG®). It operates on the principle of graphene synthesis using a liquid metallic matrix, typically copper, combined with a carburizing gas mixture. During the carburization process, carbon atoms are adsorbed and incorporated into the liquid copper matrix. The liquid state of copper allows it to become supersaturated with carbon atoms, which promotes the growth of a uniform graphene layer on its surface. This method minimizes defects such as overlapping and grain disorientation, ensuring the production of highly durable, continuous graphene sheets.

The furnace construction includes a heating chamber capable of maintaining temperatures above the melting point of copper, a controlled gas injection system for introducing the carburizing mixture, and precise temperature and pressure sensors. These sensors are critical for maintaining the optimal conditions for carbon saturation and graphene formation.

HSMG Production Unit

Control methods rely on automated systems to regulate temperature, gas flow, and the duration of the carburization process. Operators monitor the parameters using a digital interface that ensures consistency and minimizes errors during production. The resulting graphene sheets can reach dimensions of up to 100 cm x 20 cm and exhibit superior mechanical and semiconductor properties.

Conclusions:

The laboratory exercises on heat treatment technologies provided valuable insights into the principles and applications of advanced thermal and chemical processing methods. Through studying vacuum carburizing, low-pressure nitriding, and High Strength Metallurgical Graphene (HSMG) production, the following conclusions were drawn:

1. Vacuum Carburizing: This method is highly effective for enhancing the hardness and wear resistance of steel through precise carbon diffusion. The controlled vacuum environment minimizes oxidation, ensuring high-quality surface treatment.

2. Low-Pressure Nitriding: This process is essential for improving surface hardness and durability of steel components with minimal distortion. The use of advanced control systems ensures optimal nitriding conditions and consistent results.
3. HSMG Production: The innovative process of graphene synthesis using a liquid metallic matrix enables the creation of high-quality graphene sheets. This technology shows great potential for applications in electronics and advanced material engineering.

Overall, the practical application of these processes highlighted their significance in modern manufacturing, enabling the production of durable, high-performance materials tailored to specific industrial requirements.