Annealing, Hardening, Tempering – Course: Working Techniques of Heat Treatment of Steel. Methodical Guide for Instructors

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"Glühen, Härten, Anlassen"

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1. Objectives and Contents of the Vocational Training in the Working Techniques "Annealing, Hardening, Tempering"

The trainees shall have full command of the most common working techniques of the heat treatment of simple tools, testing devices and machine parts made of unalloyed steel, after having concluded the training.

– The trainees have knowledge of the purpose, the types and spheres of application of the various heat treatment processes.

– They have command of the structure and the operation of the devices and auxiliary means and are able to use them appropriately by observing labour safety and fire protection regulations.

– They have knowledge of the preconditions for heat treatment with regard to material engineering and material shaping.

– They master the various technological routines of the heat treatment processes of annealing, hardening and tempering of tools, testing devices and small machine parts.

– They are able to carry out quality controls independently.

2. Organizational Preparations

In order to ensure an undisturbed run of the instructions, exercises and instruction works it is necessary to prepare the training very well. The following measures have, among others, to be taken:

2.1. Preparation of Labour Safety Instructions

Prior to the beginning of the exercises, a short–term instruction with regard to the suitable dealing with working means specifying hints on works not involving accidents have to be given. The following features have to be imparted:

– Wear working garments, aprons and handgloves!
– Protect your eyes by means of protective glasses!

– Do not remove safety devices installed at devices!
– Do not touch cyanide salts and nitrites for melting baths with bare hands!
– Cover melting baths after use.
– Only use predried, cleaned workpieces for heat treatment.
– Take care for fire protection.
– Remove oil slicks on the floor immediately.
– Place hot workpieces only at places marked for that.
– Plut in order the tools, devices and auxiliary means after having finished work and keep them clean.
– Do careful hygiene after having finished work.

The knowledge of those hints is to be confirmed by the trainees' signatures in the control book.

2.2. Preparation of Means of Instruction

– The "Trainees" Handbook of Lessons – Annealing, Hardening, Tempering" is to be distributed among the trainees according to their number.

– Charts may be made prior to the instructions as blackboard figures.

– Coloured tables, figures, originals and models of devices and auxiliary means as well as break samples of heat–treated workpieces may be produced as illustrative material and prepared for the instructions (see section 4).

2.3. Preparation of Working Means

– The "Instruction Examples for the Practical Vocational Training – Annealing, Hardening, Tempering" is to be distributed among the trainees according to their number and intended as theoretical basis for the exercises to be carried out.

– Starting materials required for the exercises are to be prepared in an appropriate number by means of the material data given in the "Instruction Examples....

– The workshop is to be checked for a complete equipment with tools, devices and auxiliary means according to the exercises intended.

– Recommended basic outfit:

- smith's hearth with coal shovel, swatter and fire rake, stock of charcoal;
- muffle furnace with temperature gauge;
- inserts with sand and charcoal powder filling;
- melting bath for salt filling;
- hot bath for oil filling;
- quenching tanks for water and oil;
- hooks, spears, tongs, worn–out files, hammers;
- handling devices for small and medium–sized workpieces: sieves and baskets;
- cleaning agents: scouring cloths, sawdust, brooms;
- additives: clay, paper
- quenching media: water – fire–resistant, heatproof lubricating oil;
- melting agents: cyanide salts and nitrites.

The functionability of the devices is to be checked with regard to labour safety and fire protection regulations prior to the beginning of the exercises.

2.4. Planning of Training Phases

Starting from the total hours the periods for the individual training phases of this training unit are to be planned independently from each other.

For the following training phases it is advisable to take a phasing:

- for the introduction into the working techniques in the form of instructions;
- for necessary demonstrations;
- for task–related instructions for the preparation of exercises;
- for the execution of the exercises;
- for recapitulations and control works.

The following factors are to be considered when planning the periods:

- the state of training of the trainees;
- the conditions of training;
- the future employment of the trainees;
- the degree of difficulty of the training phases.

Focal point of each training phase is always the acquisition of mechanical abilities and skills by means of exercises, that feature must be given most of the time.

3. Recommendations for the Execution of the Vocational Training in the Working Techniques "Annealing, Hardening, Tempering"

The following sections include recommendations on how to organize the instructions for the trainees, the demonstrations of the working techniques as well as the exercises and control works.

3.1. The Introductory Instruction

If possible, the introductory instruction is to be carried out in a class room with the trainees. During the instruction it has to be taken into consideration that the trainees shall write necessary supplements or answers to questions in the Trainees' Handbook of Lessons – Annealing, Hardening, Tempering". The instruction can be carried out with regard to the contents given in the Trainees' Handbook of Lessons":

Purpose of heat treatment of steel

In the beginning, the trainees are to be made familiar with the term of "heat treatment" as a sequence of various processes of heating and cooling down. They shall realize that tools, measuring and testing devices as well as various machine parts must have special properties which are only reached by a heat treatment which, however, is to be carried out appropriately.

In this connection, a *demonstration* may be carried out:

A few chisel blows are to be made onto a steel plate of about 4 mm thickness by means of an unhardened flat chisel. Subsequently, this process is to be repeated by means of a hardened flat chisel. All the trainees shall examine the steel plate and the two flat chisels and draw the necessary conclusions. Subsequently, a broken chisel may be used as an example of an unsuitable heat treatment

The consideration of the heat treatment of alloy steels is necessary. The term of "alloy steel" is to be explained or recapitulated, the special properties of those steels have to be mentioned. It must be said that a correct heat treatment can only be carried out if the conditions given by the steel manufacturer are strictly adhered to, therefore, he shall supply tables specifying the appropriate temperature data. If possible, such a table should be shown.

All sections to be dealt with in the following are therefore only to be referred to unalloyed steels!

Types of heat treatment processes

The trainees may be made familiar with the most common heat treatment processes by means of the chart given in the "Trainees' Handbook of Lessons".

Those processes may be explained more in detail by means of the subsequent sections in the Trainees' Handbook of Lessons".

In addition, the special processes of "surface hardening" and "hardening and tempering" should be mentioned, but it is to be indicated that also other variants and processes are used in industry apart from the processes mentioned.

Devices and auxiliary means for heating, transportation and cooling down of workpieces

The devices and auxiliary means suitable for the production of individual parts or small series are to be mentioned and explained by means of appropriate figures, originals and models:

- smith's hearth with coal shovel, swatter and fire rake, stock of charcoal;
- gas burner to temper and flame hardening;
- Furnaces with and without temperature gauges, equipped with one or more compartments;
- melting baths for metal or salt melts as well as hot oil baths;
- sheet–metal inserts for casehardening with sand and carbon–containing powder filling;
- hooks, spears, tongs;
- handling devices such as self–tightening claws and hangers on lifting devices;
- sieves and baskets;
- quenching tanks for water and oil filling.

The effect of the different quenching media is to be explained by means of the chart in the "Trainees' Handbook of Lessons".

A short exercise of conversions is to be made for temperature data if the unit of "degree centigrade" is not used. The conversion into "Kelvin" and "Fahrenheit" is possible according to the following table:

Centigrade	Kelvin	Fahrenheit
0 °C	= 273 K	= 32 F
100 °C	= 373 K	= 212 F

Since the Fahrenheit units do not run in the same rate as "Centigrade" and "Kelvin", conversion must be effected by means of a self–made numerical line onto which these units are entered.

Principles and types of annealing, hardening and tempering

In the sections included in the "Trainees' Handbook of Lessons" the essential facts related to the mentioned heat treatment processes have been stated.

The individual principles of the procedures as well as the specific features of application are to be discussed step by step. The questions following the sections should immediately be answered in writing by the trainees and entered in the appropriate free places of the "Trainees' Handbook of Lessons".

Those answers must be checked during the discussion by a comparison! Wrong answers must not be overlooked!

Annealing:

After definition of the term, the possibility is to be made evident to the trainees on how temperatures may be assessed at workpieces without temperature gauges. As to plain carbon steels, the standard colour values may be imparted by means of the table in the "Trainees' Handbook of Lessons".

Those standard values are only to be applied if no exact temperature gauge is existing at the device to heat the workpiece!

Subsequently, the following processes are to be discussed individually:

– stress–free annealing
– soft annealing
– normalizing.

The importance of a correctly effected annealing process is to be demonstrated to the trainees. They must realize that workpieces become useless or require refinishing when the annealing is not effected correctly and expertly. It must be explained that the adherence to the holding time is vital to reach the desired change in structure. Therefore, calculations are to be made by means of the rule:

Holding time = 20 minutes plus half of workpiece thickness

The section "Control of the annealing result" should be made clear by suitable illustrative materials of various break samples.

The trainees are to be made qualified to exactly assess the appearance of the break. Subsequently, the trainees shall answer the complex of questions in the "Trainees' Handbook of Lessons".

Hint:

Now, the introductory instruction may already be finished and simple exercises for "annealing" could be carried out But it is advisable to continue the instruction with regard to "hardening" and "tempering" in order to carry out a complete sequence of exercises by means of the "Instruction Examples for the Practical Vocational Training".

Hardening:

It is recommended to continue the instruction with regard to "hardening" according to the following sequence:

– definition;
– preconditions for hardening by means of heat treatment as to material engineering;
– principle of hardening by means of heat treatment;
– types of hardening by means of heat treatment;
– hardness–related shaping of the workpieces;
– hardening defects;
– specific working hints for practical execution of work;
– hardeness measurement.

After an exact definition it is necessary to mention the material–related preconditions for hardening by means of heat treatment – the trainees must learn that not all unalloyed steels are hardenable, and that is why they must know the carbon content of the workpiece to be hardened!

Subsequently, the three essential hardening processes are to be explained:

– quenching
– interrupted hardening
– hot quenching.

As to the latter process, calculations are to be carried out regarding the holding time in the hot bath. The rule is:

$$\text{Holdingtime} = \frac{\text{Diameteror thicknessin mm. seconds}}{10\text{mm}}$$

The section "hardness–related shaping of workpieces" may be demonstrated by means of illustrative materials showing positive and negative features of shaping. The appropriate figures in the "Trainees' Handbook of Lessons" shall be used for problem discussions.

In the same connection, the discussion on "hardening defects" may be effected, it should not be done without illustrative materials.

As to the work in the workshop, specific practical hints are of special importance. Thus, it is advisable to check the procedures resulting from theory only for their practical use and to explain them more in detail. In this connection, the packing of workpieces should especially be dealt with which protects the work–pieces from scaling or carbon loss. Furthermore, possibilities to cover the workpieces having great cross–section differences are to be mentioned.

Point out: It is also important to ensure a preheating of all parts when hardening several parts in order to save time and quicker reach the hardening temperature. The complex "Hardening" is to be finished with the section of "Hardness measurement". If there are hardness measuring devices available, now deal with their application; at the same time the formation of the hardness number according to Rockwell (HRC 50) is to be explained. Supplementary, demonstrate the simple hardness test by the file test.

Tempering:

Since this process directly follows the hardening process, it must be discussed subsequently. In this connection, the relation between tempering tempering temperature and certain examples of application is of special importance; a chart in the "Trainees' Handbook of Lessons" shows this fact concerning plain carbon steels.

The connection between tempering temperature and hardness may also be illustrated by means of the following table with regard to a tempering test:

Tempering temperature	**Rockwell hardness**
200°C	63.5
240°C	62
260°C	60.5
280°C	58
300°C	56.5
320°C	54.8
340°C	54

A steel was gradually tempered according to the table, and the hardness was controlled each time as to the Rockwell process. It was determined that the Rockwell hardness decreases with increasing temperature, but steel's toughness increases.

The tempering test indicated that the tempering temperatures must be held in very narrow limits. Subsequently, explain the processes of tempering from outside and the tempering from inside.

Hint:

Now, the instruction may be finished and the appropriate exercises will be carried out. The following items as to "surface hardening" and "hardening and tempering" may be imparted in a supplementary instruction given at a later date.

Application of surface hardening and hardening and tempering

The possibilities to harden only the surfaces of workpieces as is possible by means of "flame hardening" and "casehardening" should be mentioned as specific processes of heat treatment. When explaining those **processes,** the material–related preconditions (carbon content) must be especially pointed out. Casehardening is to be demonstrated by means of the term of "carburization", an existing insert with appropriate charge material should be shown as original.

At the end of the instruction, impart "hardening and tempering" as possibility to increase strength and toughness simultaneously in general.

3.2. The Exercises

On principle, the necessary instructions as to labour safety must be given prior to the beginning of the exercises. Then, show the workshop and the existing equipment to the trainees and demonstrate its operation. It is advisable to begin each exercise by a demonstration given by the instructor in connection with an instruction related to the instruction example. Therefore, motivate the trainees to carry out the exercise with good quality. Refer to difficulties which may occur.

The exercise may be effected either thematically completed or in several phases according to the hints given in section 3.

6 exercises can be accomplished for various processes of heat treatment by means of the "Instruction Examples for the Practical Vocational Training".

The material "Instruction Examples..." includes a list of materials (starting material, tools and devices and auxiliary means) and the sequence of operations to execute the exercises as well as a clearly represented workshop diagram.

Hence, the trainees get all the necessary information for being able to systematically execute the exercises. If it becomes apparent during the exercises that the quality of the exercise pieces is not sufficient, more extensive exercises must be carried out; in that case, any waste parts should be used. When the skills have been practised enough, the intended instruction example may be produced.

The instructor must already have produced the exercise piece by himself and he must know the problems occuring in its production!

The focal points of rating to estimate the performance may thus be mentioned definitely – problematic points at the exercise piece can be referred to. During the task–related instruction, the "sequence of operations" and the workshop diagrams of the instruction examples should lie on the tables so that the trainees can write comments in their notebooks.

In order to give a general view at which exercise pieces the knowledge previously imparted should be applied, the individual instruction examples have been described in the following in short:

Instruction examples:

Instruction examples 16.1.: assembly tools

A small spiral spring (wire diameter appr. 1.0 mm) is to be made bendable by soft annealing in a smith's hearth. Bend hooks at the ends by means of tongs and, subsequently, harden and temper the spiral spring again.

(Figure 1)

Instruction examples 16.2.: marking and riveting tools

Prefabricated scriber, centrepunch, rivet header and rivet drawer are to be treated from outside by quenching and subsequent tempering. Use the muffle furnace.

(Figure 2)

Instruction example 16.3.: flat chisel and cape chisel

Prefabricated flat chisels and cape chisels are to be treated by quenching and subsequent tempering from inside. The muffle furnace is used.

(Figure 3)

Instruction example 16.4.: assembly tools

Prefabricated hexagon socket wrenches, box wrenches and screw drivers are to be treated by interrupted hardening and subsequent tempering from outside. Any furnace and separated quenching media are used.

(Figure 4)

Instruction example 16.5.: locksmith's hammer

Prefabricated locksmith's hammers are to be treated by hot–quenching and subsequent tempering from outside. Any furnace and a salt melting bath are used.

(Figure 5)

Instruction example 16.6.: testing means

Prefabricated steel straightedges, back squares and centre squares are to be treated by casehardening and subsequent tempering. A controllable furnace with appropriate insert is used.

(Figure 6)

All trainees can execute the exercises at the same time, if the material preconditions have been guaranteed (enough working means).

In that case, the trainees can execute each individual exercise independently – each trainee should get so much time he needs.

If there are not enough working means available, the trainees must be divided into groups. In this connection, it is advisable to divide these groups according to the use of the various devices:

1st group – work on smith's hearth
2nd group – work on muffle furnace
3rd group – work on any furnace and on melting bath.

If the instruction examples offered will not be used for exercises, it is possible to select other exercise pieces. In this case, it should be taken into consideration that all the working techniques discussed previously may also be practised on those exercise pieces.

Focal points for practical execution

For the execution of the works it is recommended to determine focal points for examination and estimation. Those focal points may be characterized by the following features:

– Do the trainees carefuly prepare their working places?
– Are the prefabricated exercise pieces clean and dry?
– Are the devices for heating operated appropriately?
– Are the correct temperature ranges identified?
– Are the technological sequences adhered to?
– Do the trainees adhere to the regulations on labour safety?

3.3. Examples for Recapitulation and Control

For strenghtening and checking the knowledge acquired, tasks have been assembled in this section, the tasks are given together with the appropriate answers. Tasks also included in the Trainees' Handbook of

Lessons" have been marked with the letter "A".

1. What is heat treatment?
"A" (*a systematic sequence of heating and cooling*)

2. What is the purpose of heat treatment processes?
"A" (*change of properties of unalloyed and alloy steels*)

3. According to which criteria are the heat treatment processes selected?
(*according to the purpose of application and the kind of material of the object to be treated*)

4. Which are the most common processes of heat treatment?
(*annealing, hardening, tempering*)

5. Which requirements have to be made on devices for heating the workpieces?
"A" (*temperature must be reached quickly, kept constant and must be adjustable without difficulty; steady* heating *of workpieces has to be ensured*)

6. Which devices are used for heating?
(*smith's hearth, gas burner, furnaces, melting baths*)

7. What is the advantage do of melting baths compared to the smith's hearth?
(*temperature is exactly adjustable, no danger of overheating, no scaling of workpiece surfaces*)

8. Which requirements have to be made on quenching tanks?
"A" (*quenching media must always be kept cool*)

9. Which main effects can have quenching media?
(*coarse and mild effect*)

10. Which effect has the use of a coarse quenching medium onto the workpiece?
"A" (*great strength and hardness, especially at the case, little elasticity*)

11. Which requirements have to be made on the workpieces being prepared for the annealing process?
"A" (*they must be clean, rust−free and free of scale*)

12. What principle is the basis for annealing?
"A" (*heating of the workpiece and holding of annealing temperature over a certain period, subsequently, slow cooling down*)

13. What is the purpose of stress−free annealing?
"A" (*elimination of stresses existing in the prefabricated workpiece*)

14. What is the purpose of soft annealing?
"A" (*makes further working processes for hardened or carbon steels possible*)

15. What is the purpose of normalizing?
"A" (*equalization of irregularities in the steel structure, achieving a fine−grained structure*)

16. Which rule has to be heeded for holding massive workpieces at annealing temperature?
(*20 minutes plus half of material thickness*)

17. Which holding time has to be considered when a shaft of 84 mm diameter must be annealed?
"A" (*62 minutes*)

18. Ace, to which criteria are annealing defects evaluated?
"A" (*according to the appearance of the broken workpiece*)

19. Which annealing faults may be deducted from a coarse−grained structure?
"A" (*steel was heated too long or at a too high temperature*)

20. What is the purpose of hardening by means of heat treatment?
"A" (*to make steels hard and wear−resistant for certain purposes*)

21. Which minimum carbon content must have a steel for being hardened?
"A" (*0.35% of carbon*)

22. Which effect has a higher carbon content on the mechanical properties?
"A" (*great hardness and strength, little toughness and elasticity*)

23. Which working steps are required for hardening?
"A" (*heating to hardening temperature, holding and sudden cooling down of the workpiece*)

24. What hardening temperature has to be chosen for an unalloyed steel of 0.8% carbon content?
(*780 °C*)

25. What is the characteristic feature of interrupted hardening?
"A" (*quenching is effected for a short time, in most cases first in a powerful and then in a mild quenching medium*)

26. A workpiece having irregular shapes shall be hardened by hot–quenching. Its average thickness is 100 mm. Which time has to be met in the melting bath during the cooling–down process?
(*600 seconds or 10 minutes, respectively*)

27. What has to be considered when dipping the workpieces into melting baths?
(*correct dipping according to shape, only dip dry workpieces*)

28. Why it is advisable to harden workpieces in a carbon–containing packing?
"A" (*workpiece cannot be scaled and absorbs carbon, thus avoiding carbon loss at high heat effect*)

29. What is a simple way to test hardness?
"A" (*by a file test; if the file is slipping, the workpiece is harder than the file*)

30. What is the purpose of tempering?
"A" (*to give the workpiece a useful hardness after hardening*)

31. What effect has the tempering temperature on useful hardness?
"A" (*the higher the tempering temperature, the smaller the hardness*)

32. Why can temper colours facilitate temperature determination?
"A" (*a thin oxide layer inking according to temperature is produced when heating a blank steel*)

33. Which properties can reach workpieces after surface hardening?
"A" (*the workpieces withstand great impact and bending stresses by hard surfaces and a tough core*)

34. Which steels can be treated by flame hardening?
"A" (*unalloyed steels of 0.35% to 0.6% carbon content*)

35. Which steels can be treated by casehardening?
"A" (*tough steels of a carbon content below 0.25%*)

36. Which properties shall be reached by hardening and tempering?
"A" (*at relatively high strength values, a great toughness shall be guaranteed continuously*)

4. Explanations to the Means of Instruction

Apart from models and originals of devices and auxiliary means, break samples of heat–treated workpieces are recommended as additional illustrative material. The following samples should be manufactured:

- steel of little carbon content
- steel of high carbon content
- steel having been heated too long or at a too high temperature
- steel having been heated extremely high so that it is already burned
- hardened and broken flat chisel.

Furthermore, examples for good and bad manufacture should be produced by means of the figures included in the Trainees' Handbook of Lessons". Those examples will show envisaged affects after hardening (cracks).

Existing defects should be made visible by a paint coat on a workpiece having cracks. For demonstrating the annealing colours, a table of colours including the appropriate colours is recommended which can be made as blackboards charts.