

# Computer Advisory System in the Domain of Cooper Alloys Manufacturing

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## Abstract

The main scope of the article is the development of a computer system, which should give advices at problem of cooper alloys manufacturing. This problem relates with choosing of an appropriate type of bronze (e.g. the BA 1044 bronze) with possible modification (e.g. calcium carbide modifications:  $\text{Ca} + \text{C}$  or  $\text{CaC}_2$ ) and possible heat treatment operations (quenching, tempering) in order to obtain desired mechanical properties of manufactured material described by tensile strength -  $R_m$ , yield strength -  $R_{p0.2}$  and elongation -  $A_5$ . By construction of the computer system being the goal of presented here work Case-based Reasoning is proposed to be used. Case-based Reasoning is the methodology within Artificial Intelligence techniques, which enables solving new problems basing on experiences that are solutions obtained in the past. Case-based Reasoning also enables incremental learning, because every new experience is retained each time in order to be available for future processes of problem solving. Proposed by the developed system solution can be used by a technologist as a rough solution for cooper alloys manufacturing problem, which requires further tests in order to confirm it correctness.

**Keywords:** Cooper alloy, Bronze, Modification of cooper alloy, Quenching and tempering of cooper alloy, Cased-based Reasoning

## 1. Introduction

The problem of cooper alloys manufacturing is along studied in scientific literature due to the fact, that every new type of bronze requires large set of experiments and use of additional computing techniques in order to determine influence of modifications and heat treatment operations on the mechanical properties of studied material. In [1] authors use data mining techniques in order to study influence of heat treatment on mechanical properties of bronze BA 1032. In [2] the impact of heat treatment on mechanical properties of unmodified and modified BA 1044 bronze is studied. Indicating proper cooper alloy, its modification with possible heat treatment operations requires browsing of many scientific knowledge sources and performing of several test in the case the desired mechanical properties of requested material are not strictly equal to that being presented in scientific literature. Such view of the work of

a technologist having a goal to prepare the manufacturing of a new cooper alloy indicates necessity of an additional computer tool. Proposed in this article computer advisory system should give assistance for a technologist at problem of searching of cooper alloy with possible modifications and heat treatment operations in order to meet required mechanical properties. This system should also assist by additional tests and experiments enabling future use of gaining knowledge, when the need is for searching of an other cooper alloy being characterized with similar mechanical properties.

Presented specification of computer system indicates two main aspects of its functioning: (1) problem solving by giving advices according material characterized by specified mechanical properties and (2) learning, which should base on experimentally verified results of its functioning. Such two aspects of computer system functioning suggest to use the Case-based Reasoning methodology.

## 2. Case-based Reasoning

The main paradigm of Case-based Reasoning (CBR) is reasoning by reusing of previous similar situations concerning solving problem [3]. A case-based problem solver uses the case-base, which is collection of past made and stored experience items, called cases. Every time a new problem has to be solved, a case relevant to the present problem is selected in the case-base and used by giving solution to the present problem. A distinctive feature of the CBR approach is incremental, sustained learning – each time a problem is solved, a new experience is retained, that is available for future reasoning concerning new problem situations. Case-based reasoning is, from the point of view of sustained learning, a cyclic process of solving new problems and gaining experience.

The CBR cycle is common and main algorithm of every CBR application. As presented in [3], the CBR cycle consists of 4 sequential phases: (1) Retrieve the most similar case or cases; (2) Reuse the information and knowledge in that case in order to solve the problem; (3) Revise the proposed solution; (4) Retain the parts of this experience in order to use it for future problem solving.

The CBR cycle starts when there is a new problem (in other words a new case) to be solved. In the retrieve phase, one or several similar cases from the case base are selected as relevant for the current problem. Main task in the retrieve phase is to find  $k$ -nearest-neighbour considering a specific similarity measure. The similarity measure can be inverse Euclidean or Hamming distance or can be specific modelled according the knowledge of the domain. The values of the similarity measure are not important, however important is just the preference order, that the similarity measure induces on the case base for the new problem. The preference order should enable to select one or a small number of cases, which are relevant for the new case.

The reuse phase can be very simple, when the solution is returned unchanged as the proposed solution for the current problem. In such case the adaptation of the solution is not necessary, often the solution can be just copied. On the other hand there are domains, which require adaptation of solution.

In the revise phase the solution generated in the reuse process is evaluated. The evaluation tasks takes the result from applying of the suggested solution in the real environment, what can happen by asking an expert or performing the task in the real world (performing tests). This task is usually performed outside the CBR system and makes necessary to link the CBR system with the real world domain, which the solved problem concerns. Depending on type of the application domain, the evaluation can take some time to appear (e.g. time needed for performing some experiments).

The retain phase is considered as the learning process in a CBR system. This process usually occurs by adding the revised case to the case base. Thanks to this adding, the revised solution becomes available for reuse in future problem solving and the whole system gains new experience according to the present case. The retain phase enables to learn from success or failure of the proposed solution for the present problem.

## 3. Application of CBR to the domain of cooper alloys manufacturing

Having the goal to apply the CBR methodology into the domain of cooper alloys manufacturing it is necessary to analyze the construction of all CBR notions and the run of the CBR cycle, which is theoretically presented in previous section.

### 3.1. The case and the case base

A case represents one experience item that is made in the past and that is stored in the CBR system. This experience item is related to a specified problem resolved with a specified solution, which was used in the past in order to solve the specified problem. A case can be defined as a pair:  $case = (problem, solution)$  [4]. As presented in the first section, the projected system should give advices according choice of cooper alloy, its modification and heat treatment operations in order to meet desired material properties. So, the problem is specified by desired material properties and the solution is indication of specified type of bronze with possible modification and (or) heat treatment – quenching and tempering. Formally the case  $case_i$  can be defined as:

$$case_i = ((rm_i, rp_i, a_i), (b_i, m_i, q_i, t_i)) \quad (1)$$

where:  $(rm_i, rp_i, a_i)$  describes the problem by mechanical properties –  $rm_i$  is tensile strength  $R_m$ ,  $rp_i$  is yield strength  $R_{p0.2}$ ,  $a_i$  is elongation  $A_5$  and  $(b_i, m_i, q_i, t_i)$  describes the solution by the type of bronze  $b_i$ , modification  $m_i$ , quenching  $q_i$  and tempering  $t_i$ .

The case base is collection of cases, which are used by the CBR system. The case base  $\Delta$  and can be defined as:

$$\Delta = (case_1, case_2, \dots, case_N) \quad (2)$$

where  $N$  is the number of cases in the case base of the reasoning system. The number of cases is not constant through time of the system functioning. As theoretically presented in the previous section, the retain phase enables to add new cases and enlarge the cases used in next run of the CBR cycle.

In order to explain construction of a case and the case base, an fragment of the prepared case base is presented here:

Case 1, 676, 282, 4.9, BA 1044, absence, absence, absence  
 Case 2, 816, 289, 4.1, BA 1044, absence, 950 °C, absence  
 Case 3, 849, 420, 1.5, BA 1044, absence, 950 °C, 350 °C /6h  
 Case 4, 719, 367, 11.7, BA 1044, absence, 950 °C, 700 °C /6h  
 Case 5, 640, 314, 9.1, BA 1044, Ca+C, absence, absence  
 Case 6, 801, 499, 3.2, BA 1044, Ca+C, 950 °C, absence

The first case describes the experience item, where the problem was to obtain the cooper alloys that has mechanical properties described by tensile strength  $R_m = 676$  MPa, yield strength  $R_{p0.2} = 282$  MPa and elongation  $A_5 = 4.9$  %. The solution in this experience item was the bronze of type BA 1044 without any modification nor heat treatment operations.

The problem denoted by the sixth case was related to obtain the cooper alloys that has mechanical properties described by tensile strength  $R_m = 801$  MPa, yield strength  $R_{p0.2} = 499$  MPa and elongation  $A_5 = 3.2$  %. The solution in this experience item was the bronze of type BA 1044, that was modified with calcium carbide  $Ca + C$ , heat treated at  $950^\circ C$  (quenching) and without aging (tempering).

### 3.2. Start of the CBR cycle

As theoretically presented in the second section, the CBR cycle starts when a new problem has to be solved. In the domain of cooper alloys manufacturing the new problem is related to the need of a user who has a goal to get to know the type of bronze with its possible modification and heat treatment operations in order to meet desired mechanical properties of material. The user has to input to the CBR system desired mechanical properties of bronze, that specify the problem  $p$ :

$$p = (rm, rp, a) \quad (3)$$

where  $rm$  is tensile strength  $R_m$ ,  $rp$  is yield strength  $R_{p0.2}$  and  $a$  is elongation  $A_5$  of desired material.

An example of the problem can be given as: 820, 420, 1.0, what means the user would like to get to know the type of bronze, its modification and heat treatment of a copper alloy, which is characterized by mechanical properties:  $R_m = 820$  MPa, yield strength  $R_{p0.2} = 420$  MPa and elongation  $A_5 = 1.0$  %.

### 3.3. The retrieve phase

The goal of the retrieve phase is to select in the case base a case that is relevant to the problem, which is inputted by the user. This process uses similarity measure that induces the preference order on the case base for the new problem. Similarity is usually formalized as a function  $sim : P \times P \rightarrow [0, 1]$ , which compares descriptions of two problems from  $P$  and produces a similarity assessment as a real value from  $[0, 1]$  (as presented in [5]). Taking into consideration definition of the problem (3) and the case (1), the similarity measure is proposed to be the inverse Euclidean distance between the new problem  $p$  and the case  $case_i$ :

$$sim(p, case_i) = \frac{1}{1 + \sqrt{(rm - rm_i)^2 + (rp - rp_i)^2 + (a - a_i)^2}} \quad (4)$$

The CBR system computes the similarity measure given by the equation (4) for all cases in the case base  $\Delta$ . The most similar case  $case_r$  is chosen as the relevant case for the problem  $p$ , which was specified by the user at the start of the CBR cycle.

An example of the retrieve phase functioning can be given by the problem specified as: 820, 420, 1.0 (as presented in example in subsection 3.2) and the fragment of the case base presented in subsection 3.1. The most similar to the specified problem is the case 3, which should be chosen as the relevant case.

### 3.4. The reuse phase

In the reuse phase the CBR system returns proposed solution for the specified by the user problem. The proposed solution is copied from the solution related to the relevant case  $case_r$ , so the adaptation of solution is not made.

Continuing the examples given in the previous subsections, the CBR system returns solution related to the relevant case (the case 3): bronze BA 1044 without modification, heat treated at  $950^\circ C$  (quenching) and aged at  $350^\circ C$  for 6 h (tempering).

### 3.5. The revise phase

In the revise phase the proposed in the reuse phase solution should be verified by performing experiments concerning proposed type of bronze, its modification and heat treatment operations. In the case experiments indicate other solution, the user can improve the solution, which was proposed by the system.

### 3.6. The retain phase

The goal of the retain phase is to add the experience item related to the problem specified by the user at the start of the current CBR cycle and the revised solution of this problem to the source of knowledge of the CBR system. This goal is obtained by addition of a new case to the case base  $\Delta$  of the reasoning system. This case represents the specified by the user problem  $p$  and the revised solution  $(b_{rev}, m_{rev}, q_{rev}, t_{rev})$ :

$$case_{new} = ((rm, rp, a), (b_{rev}, m_{rev}, q_{rev}, t_{rev})) \quad (5)$$

After the new case is added to the case base  $\Delta$ , the number of cases included in the case increases ( $N+1$ , where  $N$  is number of cases at the start of the CBR cycle). This extension of the case base enables to take into account the revised solution in future problem solving, which is related to the next run of the CBR cycle. As theoretically presented in the second section, due to this adding it is possible to learn the system.

## 4. Functioning of the CBR system

Presented in the third section assumptions according the project of the CBR system applied to the cooper alloys manufacturing are taken into account by the implementation of this system. This system was implemented using JAVA programming language and jCOLIBRI framework that accelerates creation of CBR systems in many domains of its use.

Figure 1 presents the graphical user interface of the implemented system. The functioning of the system is consistent with the run of the CBR cycle presented in the previous section – at the start of system functioning the user has to fill mechanical parameters of desired material, which are marked as the section (a) in Figure 1. After confirmation of parameters in the section (a), the system moves to the retrieve and the reuse phase – it

presents the proposed solution: the type of bronze, its modification, quenching and tempering, which are marked as the section (b) in Figure 1. Now the user has the opportunity to revise the proposed solution by performing additional experiments.

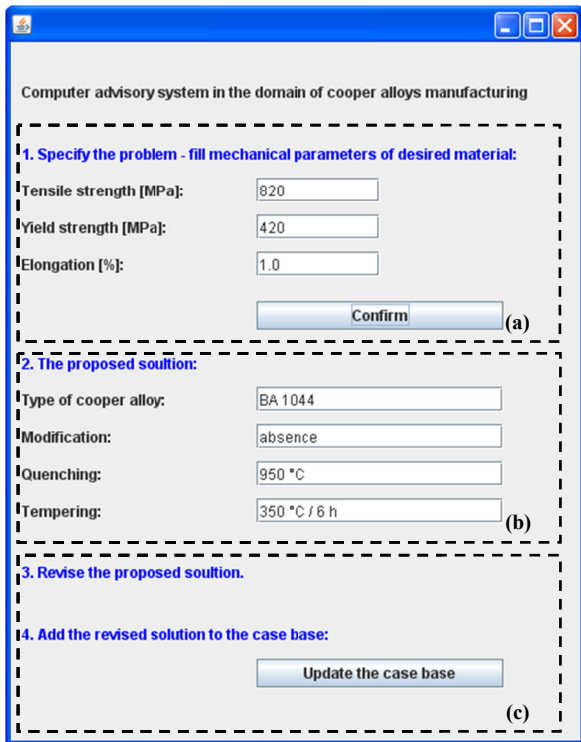


Fig. 1. The graphical user interface of the implemented system

After performing experiments it can be necessary to change proposed by the system solution or even the specification of the problem. The user has the opportunity to improve this data according to experimentally obtained results in the revise phase. After changing the data, the user can start the retain phase by clicking “Update the case base” button in the section marked as (c) in Figure 1. This action of the user enables to add a new case to the case base of the system, which relates to the experience gained by performed experiments.

## 5. Summary

The goal of presented here work was to obtain a computer advisory system that gives advices in the domain of copper alloys manufacturing. Preliminary analysis of use cases of such a system indicates two aspects of its functioning: (1) problem solving by giving advices according preparation of cooper alloy characterized by specified mechanical properties and (2) learning, which should base on experimentally verified solutions that are proposed by the system. Through the application of Case-based Reasoning (CBR) both aspects of functioning are taken into account by the system design and implementation.

The implemented computer advisory system enables to obtain advices according the type of a cooper alloy, its modification and heat treatment (quenching and tempering) in order to obtain the

bronze characterized by mechanical properties, which the user is able to specify (tensile strength  $R_m$ , yield strength  $R_{p0.2}$  and elongation  $A_5$ ). Efficiency of the system, which can be seen as the quality of giving advices, is strictly related to the content of the case base of the implemented system. The more cases in the case base, the system should give the more accurate advice as the solution to the problem specified by the user. This phenomenon is characteristic for every CBR system that needs knowledge included in the case base in order to reason according solving problems. On the other hand the CBR methodology enables also to enlarge the case base during functioning of the system – solutions given by the implemented system should be experimentally verified and after this verification should be introduced to the case base. Such extension of the case base enables to take into account the revised solution in future problem solving, which is related to the next run of the CBR cycle.

Summarizing remarks on the efficiency of the implemented system, it can be noticed that important is the continuous and sustained use of the system, what should enable to gain the knowledge being the basis for advices giving for the user. Efficiency of the system functioning should increase together with the subsequent use of the system. The sustained use of the system can also be important from a point of view of preservation of results of experiments concerning cooper alloy manufacturing. This aspect of the system use can be very significant in the case the main technologist of a manufactory can be absent in his work – in such a case the knowledge represented in the case base can support functioning of the manufactory.

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