ARCHITECTURAL SMITHCRAFT

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Abstract

The technological development of smithcraft is shown in the field of architectural works, from the beginnings up to the present. The present article describes the evolution, the historical development, and the materials of smithcraft, and describes the technological tricks of the workshops living up to now, with numerous illustrations. The last sections deal with issues of contemporary requests on wrought iron works in the fields of structure planning.

1 Introduction

In the present day, wrought iron structures occur in two fields, namely in the field of monument restoration, and in the field of recently produced works (applied art).

It is important to ensure adequate safety in the case of recently made wrought iron structures. It means adequate material quality and stability.

Contemporary monument protection aspires to balance two guiding principles. From the technological point of view, the maximum technical quality of the restored building is the main purpose. This means to bring the damaged or decrepit part or element to a quality level equal to a new one, by repair or by replacement. The other principle is the preservation of historical values. This principle aims at the preservation of as many original structures of the building as possible. It is a very difficult and complicated task that needs objective consideration to balance these two directives. Therefore it is recommended to get as precise knowledge as possible about the respective fields and possibilities.

The present paper deals with these fields of architectural smithcraft, ranging from the development and the history of this trade in Europe and in other cultures, technological possibilities, surface finishes (rust protection), and strength calculations.

2 THE HISTORY OF SMITHCRAFT

2.1 The history of European smithcraft

2.1.1 Beginnings

Smithcraft is one of the first branches of applied art that works together with architecture. The history and the tradition of wrought iron can be estimated at thousands of years. According to archaeological sources, the beginnings of iron production can be traced back to the 15th century B.C., at the area of the southern slopes of the Caucasus Mountains. Iron as a material was known in the ancient Egypt as well, but it played a much more significant role in the ancient Greece and Rome. Nothing could prove this better than the worship of the god of smithcraft, Hephaestus, and his roman equivalent, Vulcanus, among the main deities [3]. The tradition of ironwork is also several thousands of years old in the Far East, but we take only a short overview on it.

In the ancient times, the production of weapons and smaller tools represented the main fields of smithcraft. Unfortunately, most of the architectural wrought iron objects from the antiquity and from the early Middle Ages are demolished, so the examination can be started round 1000 A.D., in the Romanesque era [6].

2.1.2 Romanesque

Around the first millennium, the smithcraft, similarly to other trades, was localizable to the centres of culture, the monasteries, (fig.1) but at the end of the 11th century, civil ironwork already began to develop and became a gradually worthy rival of the clerical one. The wrought iron works of the Romanesque style follow the massive forms of the architecture; this means materiality, ponderosity and modest decoration. The first subjects of the medieval ironwork were the different kinds of gates and chest hardware. Later the range was widened with the production of locks, keys, door-knockers, weather-vanes and railings of chancels and tombs. The bronze gates of Italian and German churches were changed to oak ones because of financial reasons. At that time, boards were placed side by side without joint, so iron hinges were responsible not only for opening, but for holding together the door panel as well [2; 6]. The door hinges were branching and ended in C-shaped or bifurcate hooks. They were gilded or tinned in numerous cases [6]. Lattices on windows or above lanterns and cisterns were made for safety reasons. Artistic formation is not very frequent at this time. Symmetry is a very important characteristic of the ironworks of the Romanesque. Most of the ornaments were made in blockers. They could be welded to the shank at the end or could be forged as a part of it. [2] The works mostly were mounted with collaring or welding, but riveting was used as well in some cases.

Figure 1: Well on an cloister, Cres, Croatia

2.1.3 Gothic

The flowering of Medieval wrought iron began in the 13th century. The gunsmith trade became totally separated from the unified branches of ironwork at that time, but the whole smithcraft underwent significant changes. In the Gothic, the use of the locksmith methods, namely cold deformation techniques like chasing, carving, cutting and trelliswork, became general in smithcraft. Ironwork and smithies were modified and changed by the widening range of technical opportunities, including the invention of water-driven bellows and the helve hammer. By the development of the guild system, ironworkers also organized their guild and smithcraft improved from handcraft to applied art. By analogy with architecture, the appearance of wrought iron is changed as well. Instead of cylindrical bars and ripply sheet irons, characteristic of the Romanesque, the use of the squared section became general. Ornaments were forged out as separate parts, and mounted with riveting or welding to the whole. The former plane works gradually changed to spatial ornaments tied in bunches. Door hinges and other hardware affixed by decorated wrought iron nails, played an important role in the Gothic style as well. This time appeared the first elements produced only for decorative purposes, for example ribbon-like ornaments on door cases. Gothic locks were mainly assembled with bolts. The handle was a rarity yet. From the 14th century, numerous articles, hanging lanterns, firedogs, firebacks, candleholders, etc. were made from wrought iron, rather than from the formerly used bronze. Among the lattice-works, the window, chancel, and tombrailings had prominent significance, but screened doors also appeared at that time. These were mounted from lattice rods crossing each other, and chased plates or trellisworks were placed between them. The crossings of the lattices were often decorated with rosettes. Gothic ironworks were painted, gilded, or tinned, but natural colour iron was not rare, either. [6]

2.1.4 Renaissance

From the 15th century, the Renaissance gained ground, first in Italy, and later all over Western Europe. The new style, similarly to the case of other branches of art, brought about many changes in the field of smithcraft as well. Parallel to forging techniques, methods of the locksmith trade - chiselling, carving, and chasing - were developed to a higher level as well. Smiths used wires, thin cylindrical bars, and plates as initial material. Helical decoration became popular again, as it had been in the Romanesque, but this time in a much more complicated form. In contrast to the Middle Ages, numerous works of Renaissance craftsmen were inherited by posterity. Door structures were framed already, and the former, giant hinges were replaced by finer, more delicate hardware, just as door-knockers were replaced by house-bells. Wardrobe and door handles, chandeliers, consoles, lamps, hanging lanterns were prepared continuously. Etched and chased works are important characteristics of Renaissance locks. Keys were similarly richly decorated. The use of different types of screens spread increasingly. Wrought iron stair, balcony, tomb, chancel, and pulpit railings, trade signs, the consoles of spouting horns, grave crosses, fences and the garden gates of the palaces of the nobility became more and more popular. Lattices on windows still had only a functional role. The protruding, basket-shaped window screens that were prepared from thinner bars this time,

Figure 2: Fence of the Place Ladislas, Nancy, France

with the purpose of giving more light, are characteristic works of the style. In addition to the former techniques, noble metal inlays and etching appeared as new techniques of the Renaissance [6].

2.1.5 Baroque

In the 17th century the classical composure of the works of architecture and applied art was disrupted. Stable, constructive forms were changed by more dynamic and more ingenious ones. Ironworks became increasingly spatial. Nature imitating decorations were characteristic instead of styled works. C-, G- and S-shaped snails, acanthus leaves, calyciforms, and palmettes were frequently applied. The development of iron production, the spread of the shape-mill in the 18th century had a favourable effect on the ironworker trade. Plates for lower prices and better quality became available, which made popular the cold chasing technique at the fabrication of leaf-shape decorations. Similarly to previous styles, window and door hardware were characteristic of the Baroque as well. Due to the development of wood carvings, ironworks were pushed into the background at the interiors, but they played a larger role at the architecture of the outer areas. Stair, balcony, and corridor railings, fences, balusters were made for new castles, courts, and mansions at the end of the 17th century.

In the 18th century, large-scale monumental wrought iron works appeared. Significant examples include the ironwork of the late-Baroque architectural composition on Palace Stanislas in Nancy, France. (fig.2) Plenty of perdurable Baroque works were fabricated in the field of smaller objects as well, like the continually increasing amount of trade-sings, inn-signs (fig.3), grave crosses, weather-vanes and bell yokes. In the Baroque the most frequent finishing method was blackening, but examples of tinned, gilded, and bi-, or tri-coloured works could be found as well [6].

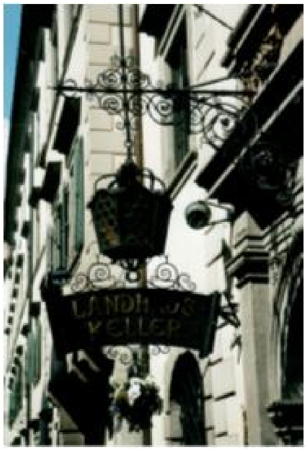

Figure 3: Inn-sign, Graz, Austria

2.1.6. Rococo

Rococo ironwork continued the art of the Baroque, but it was richer and unbridled in the way of decoration, and finer elaborated in details. The former symmetric way of construction - also characteristic of the Baroque - totally disappeared, or it became occasional. Decoration motives were decreasingly moderate. Unscrewed acanthus leaves, crested snails, bunch and flower-braids, rose, sunflower, and other flower ornaments were characteristic. On the other hand, door hardware became simpler, caps appeared around the keyhole as finely decorated metal sheets, and the long hinges disappeared. (fig.4)

The initial materials of smithcraft were sheet irons and the quadrate iron bars in this time. Cold forming played a more and more significant role in ironworks [6].

2.1.7. Classicism and the 19th century

The surfeit of the Rococo is followed by the more moderate Classicism. Ironworks were constructive again, decorations imitated ancient Roman and Greek forms, and the initial materials were the same as in the former periods. Due to the spread of cast iron, the wrought iron technique was pushed to the background. Even smaller objects were made from other different metals. The 19th century is characterised by the diversity of the Empire style, Historicism, and Eclecticism.

The cast iron industry, rapidly developing in the first half of the century, almost totally replaced the wrought iron technique; only at the very end of the century did demands for smithcraft revive. This period is characterised by varicosity, mixed, provisional forms, locksmith's (cold-forming) techniques, and the production from elements prefabricated in millworks. At the end of the 19th and the beginning of the 20th centuries, new spiritual trends appeared, demanding a breakaway from former tendencies and searching for new ways. The birth of different folksy styles and the Art Nouveau were the consequence of this process in Hungary. These styles, especially the Art Nouveau, were favourable to a new development of the wrought iron technique (fig5.)[6].

2.1.8. The 20th century

Modernism was born in the first half of the 20th century as a continuation of previous developments and as a new constructive mentality, which brings functionality into prominence, and uses the rhythmicity of forms and the nobility of proportions and materials as tools [6]. The use of ironworks became occasional and experimental; wrought iron is not anymore among the basic architectural means. Despite the fact that nowadays the trade of ironwork seams to upswing, wrought iron is mainly used at monument restorations and as an independent work of applied art.

2.2 Smithcraft outside Europe

2.2.1. The Far East Iron and ironwork were known all over the word. Although this branch of industry has not had such an overriding importance in other civilisations as it had in Europe, numerous other ancient cultures have a high-level technique of iron processing, like the great civilisations of the Far-East, India, China and Japan.

In the ancient China, iron was known for long, but among the metals used, bronze played the most important role. China has gone far ahead of Europe at the field of bronze working, that could be the reason why the use of iron was limited to a smaller scope.

Figure 4: Decorated keyhole, Graz, Austria

Although Indian steel had been famous already at the time of the ancient Greeks, iron had not stood at the first place in terms of tool producing in this region either. Iron as a material had already been known in India in the 12th century B.C. [8]. Some sources mentioned the processing of iron and the use of iron weapons in the Yajurveda Samhita district round 1000 B.C. Later, in the 5th century B.C., Ktesias related about two Indian swords that he had got from the Persian king. He speaks about their quality with great acknowledgement. Another note provides evidence of the fact that the Malloi tribe gave a greater amount of Indian steel (”Ferrum Candidum”) to Alexander the Great in the 4th century B.C. [8;9]. Last but not at least, we are informed from the writing of Periplus that in the 1st century A.D, Indian steel was exported to numerous places including Africa or Abisssina [9].

Indian weapons and armours were famous, not only for their good quality, but also for their rich decoration [8]. Although ironwork was characterised by weapon production, considerable amounts of works were made in the field of ornaments as well. Famous examples are the wrought iron gate of the tomb of Shah Alam in Ahmedabad, or the iron column in the courtyard of the Kutb Mosque in Delhi, from the 4th century, which has not corroded for 1500 years, despite the effects of the weather it endured in unchanged condition [8].

In spite of these facts, copper, brass, and bronze are much more frequently used than iron in this area as materials of everyday utensils. On the one hand, this can be explained by the 1083şC melting temperature of copper that can be reached much easier than the melting temperature of iron that is one and a half times as high. On the other hand, the first iron objects were made from meteorite iron that had no connection to underground iron resources, which remained hidden [9]. The development of Japanese ironwork was parallel to the Indian one. The production of weapons (especially swords) was also characterised by the priority of iron, other fields of handworks were mainly dominated by other metals [11].

In general we can say that in the cultures of the Far East the role of iron was mainly confined to the field of weapon production, or rather sword production, but significant works can be found among them.

2.2.2. The Middle East The metalwork of Islamic countries is set upon a Persian basis. In the beginning, the use of noble metals was significant; later on, after the prohibition of those uses, copper, tin, and bronze came to the limelight. Iron and steel were mainly used for weapons. The works of the craftsmen of the Middle East were famous and popular for their decoration, not only in the Arabic world, but in Europe as well. In Hungary, the Turkish occupation played a determinant role in the spread of oriental articles [12; 13]. As regards everyday utensils, iron has been used in general from about the 18th century in this area [13].

2.3 History of Hungarian smithcraft

The wrought iron technique had been known already by the conquering Hungarians. Horse appointments, weapons, and some parts of the chart were made by smiths. We know very little about Hungarian ironwork before the Tatar invasion. Our relics from that time were destroyed in the storms of the past [6]. Hungarian ironwork developed simultaneously with the European one, at most with a delay of one or two decades compared to the German or French example, but the survived relics gave evidence of the same artistic level [6].

In medieval Hungary, the craftsmen who made the wrought iron elements of buildings belonged officially to the locksmith guild. Some smith masters stood pre-eminent among locksmiths by learning the wrought iron technique [2].

Up to the 19th century, the guild system had been general. Smiths and locksmiths, after spending their apprentice years, went to their compulsory three-year journey. After spending the journeyman years and attaining majority, the manufacturing of the masterwork could follow. If the masterwork was considered to be adequate, initiation to the guild could take place. Joseph II. established Sunday drawing schools with the aim of raising artistic level at the end of the 18th century. Completion of this school was the condition for liberation from apprentice to journeyman by order [2].

The artistic use of the wrought iron technique became general by the 13th century in Hungary. From this period on, mainly church related relics are known as these buildings were lasting and they were protected from the demands of continuous change [2].

Figure 5: Wrougt iron entrance, Budapest, Hungary

Hungarian Renaissance ironwork followed the example of the German one. During the time of the Turkish occupation, smithcraft went into a decline in most parts of the country. Considerable industrial activity was observable only in the royal towns of Upper Hungary [6].

Baroque relics, however, can be found all over the country, in consequence of the disposition to build after the Turkish times. Fences, stair and balcony railings of castles and mansions, as well as decorated gates were made in Hungarian workshops. Rococo ironwork had a similar significance as the Baroque one in Hungary, and the works of this time belong to the most prominent ones in Europe as well [6].

The 19th century is characterised by the upsurge of the locksmith technique, in contrast with wrought iron, corresponding to international tendencies. However, this did not mean the decline of the craft. Hungarian ironworkers obtained numerous international acknowledgements this time [2; 6].

3 TECHNOLOGY OF SMITHCRAFT

3.1 The operation sequence of forging

i. Design

The shape and the decoration are developed during the design. The drawings are accurate to dimension, and contain technologically elaborated details. Plane cut-patterns (gauges) are made for the spatial forms. Following the design, the smithmaster produces, one after the other, the parts that can be forged as independent details of the whole work.

ii. Row-shaping

The working process usually begins with one of the basic methods (e.g. stretching, joggling, etc.), or a series of them. The more complicated methods are made by two or more craftsmen. The heating assistant of the smith is responsible for holding the iron in the fire. The smithmaster directs the work of the assistant smiths

Table 1:

Heat colour	Temperature $[C^\circ]$
dark brown	600
brownish red	650
dark cherry	700
cherry	750
light cherry	800
red	850
light red	900
orange	950
yellow	1000
light yellow	1050
yellowish white	1100
candid	1150-1300

by the signs of his hammer. The first assistant smith stands at the right hand, and if the work needs more people, the second one stands at the left hand [6].

iii. Fine-shaping

The basic methods are followed by fine shaping and decoration (e.g. carving, chiselling etc.) of the work.

iv. Assembly

The work usually begins with the completion of the more complicated smaller parts and the structural elements (frame), followed by the assembly of the whole object. This can be performed by the various mounting techniques mentioned below.

v. Surface treatment

As the last phase of the assembly, some surface finishing is applied.

vi. Installation on site

The completed object must be installed on site. This step occasionally preceeds surface finishing methods.

3.2 Technological methods of smithcraft

Although many different techniques are used in the procedure of wrought iron works, originally the basis of smith techniques is hot forming. In the case of hot forming, at the adequate temperature, the material remains homogeneous, but the atoms of its crystal structure, in consequence of external mechanical effects, can slide on each other, thus become easily malleable [3]. The most important techniques are the following:

Heating

Heating (fig.6.), in fact, is not an independent technique, but an antecedent action of all hot forming methods. Heating is carried out in the smith's hearth. (fig.8.) Precisely that part should be heated that will be formatted [1]. Different extent of heating is required for the different methods. The smith can observe the temperature of the iron from its colour (Chart 1.) [6].

Stretching

Stretching results in a reduced area of the cross-section and increased length [1]. Stretching is carried out with the continuous, rhythmic rotation of the iron during hammering. It is important to take care about the constant rhythm during the process and the right angle of the hammered planes, so the cross-section remains square-shaped after stretching. Smiths should not make dints in the surface, either [1; 3].

Upsetting

In case of upsetting, heading, or riveting, the cross-section becomes larger than it had been before in contrast to the stretching [3]. It is especially important, in case of upsetting, only to heat the part that has to be thickened, because exactly the heated part will be transformed [1]. It is possible to upset parts in the middle and at the end of the iron [3]. The weight of the hammer and the force of hammering are important factors of upsetting as well [1].

Broadside rolling

Figure 6: The heating in the furnance

Broadside rolling means the lateral stretching of the material; in other words, in consequence of the process one of the dimensions of the cross-section enlarges, the other decreases, without significant change of the length. Broadside rolling can be made axially symmetric, or only on one side. The process is performed with the poll of the hammer on both sides of the iron, hammering in the direction of stretching, in constant rotation. At the end of the process, the surface is sleeked with the flat end of the hammer, and finally with a smith's fuller. Broadside rolling is checked by a gauge. If the form and the dimension correspond to the gauge, the process is adequate [1].

Splitting

In case of splitting, discontinuity is caused in the material (cut in). If it runs through the whole cross-section, it is called cut-off. The sharpening-angle of the hardened steel chisel-hammer changes in accordance with the task. In order to avoid a sudden breakthrough, a $3-4mm$ thick mild steel sheet is placed on the anvil, which protects the edge of the chisel-hammer and the anvil as well. In case of one-sided splitting, the edge of the chisel-hammer can run into the softer steel sheet [1; 3].

Holing

The holing process is related to splitting. The work is signed with a pointer and split on both sides, then broken through with a drift hammer. The size and cross-section of the drift hammer can vary, in accordance with the required result. In order to prevent extenuation of the material, the area of the hole is bloated before the process [3].

Joggle

The joggle process causes a joint-like tailing of the cross-section. The joint is not cut but hammered on the anvil. The joggle can be one-, two- or four-sided, according to the way of hammering that can be made from one, two or all the four directions.

Bending

Traditionally, bending was performed with two hammers. The work was fastened with a larger, so-called sledge-hammer and bended down on the side of the anvil with a smaller smith's hammer. If the material is not fastened, it buckles in an S-shape above the bending. The way of bending can be arched or angled. Angled bending is made in a bench vice. The work is bended in the vice, pulled away a bit and upset back at the corner

Smith-welding

Smith-welding is one of the most routine-requiring methods; in fact, it is the merging of two separated pieces of material close to the melting temperature. During the process, the ends of the works are slowly heated to $850°C$ up till the middle of them have reached this temperature, then they are fast heated to $1350°C$. Taking out the irons from the fire, some accessory is used on the surfaces of the welding, in order to avoid the further formation of forge scale. If both of them are in plastic state, close to melting, the pieces should be hammered together with accurate strikes. The welding is correct if no scale remains between the surfaces [3]. The compound of the welding accessory could be various, made according to different, traditional and well-kept formula, but most of them were a flux of borax and quartz-sand, which deoxidized iron-oxides. Steel is easily weldable if it's coal-bearing is beneath 0.3% or if it is alloyed with manganese [3].

Other methods

Apart from the above-mentioned methods, numerous other ones are used at the production of wrought iron works, for example the mostly cold forming decoration techniques. These belong to the processes of the locksmith trade, but the overlapping of the two crafts is unquestionable. Chiselling, grooving, chasing, winding, and the different kinds of enchasing techniques belong to the most frequently used decoration techniques

Mounting techniques

Different mounting techniques are used for assembling of the whole wrought iron work from forged elements:

- *Collaring*

  Collaring is a frequently used solution and known for a long time. The parts are held together by means of a piece of quadratic or semicircular cross-sectioned iron collar. It can be made by cold forming up to $5-6mm$ thickness. Very important is the precise sizing of the collar. This is checked with a piece of rope and by test-collaring as well [6].

- *Riveting*

  Riveting is also one of the oldest methods for fastening two parts together. Regarding the dimensions of cross-sections the rivet should precisely seat in the hole. At the ends of the rivet, a length of 1.5-2 diameters should be stuck out from the hole. If the size of the diameter is below $10mm$, cold-riveting can be performed as well [1]. According to the way of the process, the rivet can be lowered and headed [6].

- *Mortising*

  In case of mortising, the parts of the wrought iron structure are connected with pins to each other, like wooden structures in carpentry [14].

- *Threading*

- This process means that iron bars are infilled into punched holes. The works produced this way can be from quadratic, circular, or flat steel bars, with acute or right-angled crossings [6]. Threading is frequently used for window grills.

- *Other mounting methods*

  Different parts of a work can be mounted to each other with screwing and welding as well, but these rather belong to the methods of the locksmith trade.

3.3 Surface finishes

Corrosion is the greatest enemy of wrought iron works (fig.7), especially architectural wrought iron objects, which stand in numerous cases in the open air. In contrast to some other metals (e.g. aluminium), the oxide on the surface of the iron , does not form a continuous coating, but it flakes away and allows corrosion to get deeper and deeper. This process results in a continuous diminution of the material, the decrement and at the end the final failure of the structure. The surface of the iron has to be protected against corroding effects by some metallic or non-metallic coating. The most frequently used ones are:

Figure 7: Effect of the rust

Oil-burning

In case of oil-burning the work is smeared with linseed oil or spent Diesel oil, and at $300-400°C$ it is burned to even black colour. At the end of the procedure the object is coated with a clear lacquer [3; 6]. If the natural metallicity or the wrought iron character of the object has to be emphasised, it can be rubbed up with a brush or abrasive cloth before lacquering. Oil-burning does not provide durable protection, therefore it is mainly suitable for objects placed indoors [6].

Blueing

The technique of blueing has a mainly decorative role, but to a certain extent is also inhibits rust. In this case the surface of the iron is heated to approximately $300°C$ and it becomes bluish-coloured. The shade of the colour depends on the cleanness of the surface [14].

Dipping

In the case of dipping, the iron object is bright-finishe, and dipped into an acidic solution (salt acid, nitric acid, sulphuric acid). An even, brownish surface is left over by removing the oxide layer with a wire brush [4]. Dipping nowadays is rarely used because of its limited durability. It is also used only for the surface protection of objects indoors [4].

Painting

Painting, as every surface finishing method, begins with the cleaning of the surface. Cleaning can be a mechanical or chemical procedure. This is when the surface is unoiled and superfluous oxide is removed. After cleaning, the work is supplied with an antirust base coating (e.g. minium), then after this layer becomes dry, it is painted. Paint can be applied in one or more layers. After the application of the base coating, surface defects can be corrected by rubbing and knotting if necessary. Certain paintings, besides the base coating, consist of a mat intermediate layer and an enamel coverpaint, but single-layer enamel paints applicable directly on the corroded surface also exist [3; 6].

Dip-galvanising

The essence of the procedure is to create a coherent zinc layer on the surface of the object. The process begins, similarly to painting, with the preparation of the surface (uncoiling, removal of oxide); then the work is dipped into $450°C$ fluid, clean to metal zinc. The dip-galvanised surface can also be painted. In this case, an adhesion supporting layer precedes the base coating [3]. Cold formed objects have to be annealed before the process of dip-galvanising. All parts of the dip-galvanised object should be reached by the molten zinc. Riveted works can not be dip-galvanised [3].

Metal spraying In case of metal spraying, corrosion resistant molten aluminium or zinc is sprayed with gas-burning hot spraying equipment onto the cold steel, in the specified thickness. This procedure is economically applicable for small-sized objects as well. Sprayed surfaces must be coated with base and cover painting [3].

Gilding The gilding is a technique applied for a long time on prominent places. Fire gilding was already known in the ancient times as well. The essence of the procedure is to drive the amalgam of the gold upon the surface and burn it on. In consequence of the process, a thin noble metal cover builds up. The galvanised gilding technique has been used since the 19th century. The surface of the metal is covered by copper, and it is placed into the galvanising solution as a cathode. The gold settles on the surface of the object as a thin layer.

Figure 8: The smith’s heart

3.4 Tools of the workshop

The most important questions about the arrangement of the smithy are sunlight, luminance, and adequate ventilation. Orientation to the north is advantageous because in this case direct sunshine cannot disturb the work process. If it is not possible, this problem should be solved by shadowing. Ventilation was traditionally arranged by large windows. Nowadays artificial ventilation is used frequently. The pavement of the workshop is traditionally paddled clay, recently it is rather made of concrete, but round the bench it is made from block-wood. The place of the tools and other equipment is specified in a way to ensure unhindered work [6].

3.4.1. Smith’s hearth

The structure of the hearth (fig.8.) is based upon thousand-year traditions [3]. As regards its material, we can distinguish masonry and cast-iron hearths [6].

The furnace is the central part of the hearth. The iron is heated in the furnace, among hot coal. The frequent cleaning of the furnace and the continuous supplementation of the burnt away coal are very important. To avoid the spread of the fire, the furnace is bordered by quarter-rounded cross-sectioned buffles. The water-tank is placed near to the furnace. It is used for sprinkling water into the fire and cooling down the overheated tools. The

Figure 9: The anvil

hood is placed above the furnace, collecting the smoke and driving it into
the chimney through a flue.

Another important part of the hearth is the air blower that supplies the furnace with sufficient air. The supplement of air should be precisely regulated for the adequate quality of the work. An air controller handle is used for regulation, but it is not a part of every hearth [3; 6].

In fact, the fire irons, the poker, the coal-shovel and the fire sprinkler belong to the hearth as well.

3.4.2. Anvil and stool (fig.9.)

As regards their material, we can distinguish wrought iron and cast steel anvils. The ideal weight of an anvil is $250 - 280kg$. The working surface reaches adequate hardiness and abrasion-proofing by cementation [3; 6].

The stool serves as the propping up of the anvil. It is usually made of the 60-100cm long part of an oak trunk close above the roots. The stool is about half of its height sank under the floor as a foundation, and it is protected against cracking with shrunk-on bands [3; 6].

3.4.3. Bench vice

The vice is used for bending hot materials and for chucking gauges. (fig.10.) The average weight of the vice is $20 - 50kg$ [3].

x

The hearth, the anvil and the vice, as the three most important pieces of equipment for the smith's work are traditionally arranged in a triangle in the smithy.

3.4.4. Hand tools

Hammers

The hammer is the essential tool of the smithcraft. (fig.11.) Different hammers are used for different purposes, like the well known, $1 - 3kg$ weight forge hammer; the similar looking, but much heavier $(6kg)$ sledgehammer; or the cross-pane hammer, which is exactly the same as the sledge, but its poll stands in transversal direction (parallel to the pole). There are several further hammer types used in the smithy, like the spreading-hammer, the smith's fuller, the ball-peen (embossing) hammer, the drift hammer, the peening hammer, and the different chisel-hammers, etc. The pole of hammers is usually made of ash-wood [6].

Anvil tools

Anvil tools can be placed in a rectangular hole in the plate of the proper anvils. According to the way of use, anvil tools can be various, including cutter, twister, ball-peen, or fork-shaped tools; but the different types of bottom swages, the taper iron for anvil, and the support for top fullers belong here as well [3;6].

Tongs, pliers

At forging and heating, different kinds of tools are used for griping the iron (fig.12.) Pliers have shorter shanks, and are mainly used for forging. Longer tongs are more suitable for heating. Most of these tools, occasionally all of them, are made by the smith. The most frequently used ones are flat, long-nose, and side bent pliers. The head of the proper tongs should be heat resistant and the shank should bear the stress of the grasp. In case of larger pieces of work, gripping rings are used on the shanks [6].

Figure 10: The anvil

Other tools

Besides the basic (hot forming) methods, numerous other activities happen in the smithy that need further equipment. These are mainly the tools of the cold forming. Nowadays, modern devices like hand welders, bench drills or grinding-machines are also used for some purposes.

4 FORGING MATERIALS

4.1 Raw materials

4.1.1. Iron

Although in certain cultures all branches of metalwork (e.g. the copper work as well) are classed among the smith trade, for us the technique of wrought iron - considering its material - can be attached to iron, to be more precise, to steel. The chemical symbol of iron is Fe, its density is $7.88g/cm^3$, the melting point is $1536°C$ [3]. Elemental iron can be found only in meteorites, but it has several appearances as iron-ore (magnetite, hematite, limonite, pyrite, siderite, etc.). The iron-bearing of these minerals is $20-60\%$. The ore is prepared for melting with grinding, milling, and roasting. Melting is made in an iron furnace. The iron is freed from superfluous coal-bearing and other contaminants here. The resultant products of the metallurgical process are crude irons or steels of different coal-bearing. The iron blocks produced in the furnace are heated again and tubes, iron sections, as well as rod or sheet irons are produced by a rolling process. These can be the initial materials of the smithcraft [1].

4.1.2. Steel

Iron and steel types are classified by their coal-bearing. Iron-carbon alloys can contain $0.06-6.67m\%$ of coal. The alloy is classified as pure iron under 0.06m% of coal-bearing. If the carbon-bearing is over $6.67m\%$, elemental coal will precipitate out of the alloy [1; 3]. Materials of $2.06-4.5m\%$ coal-bearing are called crude iron. In consequence of the fact that crude iron has no plastic state, it is only suitable for iron casting. Iron-carbon alloys are called steel under $2.06m\%$ of coal-bearing. According to the field of application, steels have two types. Steels of $0.8-2.06m\%$ coal-bearing are more rigid and harder, these are called tool steels. Steels of $0.2-0.8m\%$ coal-bearing are softer and more workable, these are called constructional steels [1; 3]. Steels of $0.2-1.7m\%$ coal-bearing are suitable for forging, but ones with less than $0.8m\%$ coal-bearing, namely constructional steels are preferred. Steels of over $1.2-1.3m\%$ coal-bearing are forgeable with difficulty [1; 3].

The characteristics of steel depend on alloying metals, not only on coal-bearing. Nearly every kind of steel contains silicon and manganese, so these are called general alloying elements. General alloying elements increase the strength, but decrease the ductility of the steel. The alloying elements that are responsible for the special characteristics of the steels are called active alloying elements. Active elements include chrome, nickel, vanadium, tungsten, cobalt, and molybdenum. Chrome increases strength, but decreases ductility; nickel increases strength to certain extent only, but causes a higher ductility. Chrome-nickel steels are high-strength, heat resistant, in most cases also acid-resistant. Tungsten and vanadium alloys are high-strength steels as well.

Figure 11: Hammers

4.2 Initial materials

At the beginnings of smithcraft, the smith master forged the initial material (iron rods and sheets) from large iron blocks, in the smithy by himself. Later on, these iron products were made in tilt-mills, first with manual work and with water and steam driven machines later. The large-scale industrial production of iron started in the 19th century. The different kinds of hot-rolled steels and iron sections appeared this time as well. [2] Nowadays, standardised, hot-rolled or cold-drawn iron rods (with round or rectangular cross-section), or different kinds of steel sheets are used for forging. [1]

4.3 Structure of the material

Chemically pure iron, as every metal, has got crystalline structure, where the atoms form a space lattice. Regarding its arrangement, iron has two different lattice types. At room temperature the so called body-centred cubic lattice exists. In the BCC lattice, the iron ions are at the corners and in the middle of the cubic elementary cell [3].

The body-centred cubic lattice, when heated beyond $911°C$, transforms to a face-centred cubic lattice. In the FCC lattice the iron ions are at the corners and in the middles of the faces of the cubic elementary cell. The steel is easily workable at this temperature [3].

Figure 12: Tongs and pliers

qsubsectionThe quality of the material

For contemporary works, the materials of the construction industry are used [3]. The qualities of steel types and the related mechanical properties are shown in Chart 2. [15].

We do not have systematic databases about the qualities and properties of materials in historical constructions.

Chart 2.

Grade of the strength group	Codes of steel quality and numbers in the adequate Hungarian standards		Thickness mm	Design strength N/mm^2			
				Tension and compression	Shear	Bolt-bearing property	
						Rivet or Bolt	Average value on the surface of pins
			t	σ_H	τ_H	σ_{pH}	
37	A 0	MSZ 500	≤40	175	100	305	220
	A 34, A 34 X, A 34 B			190	110	330	220
	A 38, A 38 X, A 38 B		≤50	200	115	350	240
	37 B, 37 C	MSZ 6280					
	LK 37 C	MSZ 6259					
	A 35 A 35 K	MSZ 29/2 MSZ 29/3					
45	A 44, A 44 B	MSZ 500	≤40	230	130	400	280
	45 B, 45 C, 45 D	MSZ 6280	≤40	240	140	420	300
	LK 45 C LK 45 D	MSZ 6259					
	A 45 A 45 K	MSZ 29/2 MSZ 29/3					
52	52 C, 52 D	MSZ 6280	≤50	280	160	490	360
	LK 52 C LK 52 D	MSZ 6259					
	A 52 K	MSZ 29/3					
58	E 420 C E 420 D	MSZ 6280	≤16 16<t≤35 35<t≤50	320 310 300	185 180 175	520	420
64	E 460 C E 460 D		≤16 16<t≤35 35<t≤50	350 340 330	205 200 190	550	460

5 WROUGHT IRON STRUCTURES

5.1 Characteristic structure types

Speaking about wrought iron structures, in the first place we think about wrought iron structures in architecture. This article does not deal with works that are made for exclusively artistic purposes (e.g. statues), and the non-architectural wrought iron objects of other fields.

5.1.1. Vertical structures

Railings, lattices Rails (fig.13.) and divider lattices are usually designed for the horizontal load of $0.3kN/m$, or in case of thronging crowd (e.g. theatres sports establishments, etc.) $1.5kN/m$, in 1m height according to the MSZ 15021/1-86 standard. In this case, the safety factor is 1.4 [3].

We should calculate with wind action only in case of outdoor railings. The way of the calculations is identical to the design of fences [3]. Railings can be fixed in walls (e.g. between two pillars), but most frequently they are retained in the floor by vertical bars [3].

Fences

In case of fences, outdoor lattice works, and railings, the effect of the wind has the most important role. The design value of actions is wind action taken into account by the shape factor. The shape factor is different for different geometries of the fence. Occasionally, fences also have a special protective role (e.g. near high-traffic roads, the fence should not let through the impacting vehicles in case of an accident). In these cases, the object has to be designed for these actions as well.

Gates

Wrought iron gate structures (fig.14) contain two main parts, the wing and the pillar. In a simpler case, the wing is hung up on a masonry construction. If the pillar is also part of the wrought iron composition, it is usually a cantilever girder loaded by the weight of the wing on the mounting points.

The wing is planar structure or lattice-work. The overhangs can be regarded as a three-rod support, counting with a horizontal force at the upper overhang point and with a horizontal and a vertical one at the lower overhang point. At gates, the design value of actions is counted according to self weight and wind action. Occasional climbing on the wing can be considering as variable load [3]. The effects of opening and closing, and in special cases, power-driven movement can cause dynamic loads.

5.1.2. Horizontal structures

There are also horizontal wrought iron structures (e.g. canopies, gratings etc.), but much less than vertical structures. The design value of the actions in this case is counted from self weight, live load, and in open air, from wind action and snow load. (fig.15)

5.1.3. Cantilever structures

Cantilevers constitute a significant part of wrought iron structures. Stand-alone supports (consoles), include trade-signs, inn-signs, or lamp supports, but the girders of balconies or other horizontal structures belong here as well. While the former are designed for self weight and wind action, the latter ones should also correspond to the loads of superimposed structures (self weight, snow load, live load, etc.).

Cantilevers can vary in terms of their construction, but these are pin-rod triangle or trellis girder structures in most cases. According to the way of bracing, we can distinguish overhung and lower knee braced structures [3]. In case of wind action $c = 2$ formal and $\mu = 1.2$ dynamic factors are used for cantilever structures [3].

5.1.4. Stand-alone works

Lampposts, candelabras, statue-like works, etc. are stand-alone objects. Most of these objects are fixed in the floor. The design value of actions in this case should be calculated from self weight and the

Figure 13: Railings in the castle of Krasznahorka, Slovakia

Figure 14: Wrought iron gate Betlér, Slovakia

in the open air, from wind action, which changes in consequence of the built environment (e.g. distance from the surrounding buildings).

5.2 Special questions of structure design

Strength calculations for wrought iron structures are necessary in two cases.
The first case is monument restoration. In this case, we should examine a historical structure for decision on the method of the treatment (e.g. restoration, partial or complete replacement). The second case is newly-made wrought iron works in the field of applied arts, if safe use demands strength calculations.
Rarely can be found references in technical literature about the strength calculations of wrought iron structures. These works make proposals for designusing strength calculations for ordinary constructional steel structures only. The following is a study of the facts that could cause differences in calculations of wrought iron structures made with traditional techniques, as compared to constructions made from well-known quality steel products.

5.2.1 Loads of wrought iron structures

In the case of structural design, both Hungarian practice and European standards use the partial safety factor method, therefore loads and effects are calculated with separate safety factors. [3].
The loads of wrought iron structures can be divided into two groups: permanent and variable loads. Self weight and live load belong to the first one; meteorological loads (e.g. wind action or snow loads) and other variable loads belong to the second one [3].
Numerous factors should be considered at calculating loads. Different factors affect objects inside buildings and in the open air, respectively. In the case of variable loads, the chances of simultaneity also have to be considered, therefore the simultaneity factor is used. In case of more than one simultaneous effects, the worst condition of loading should be taken into account as the design value of the actions [3].

Figure 15: Wrought iron balcony, Betlér, Slovakia

Self weight

Self weight should be calculated as load at every wrought iron structure. It is the simplest load. At wrought iron supporting structures, superimposed load has also be taken into account. The calculation process in this case is the same as it is in case of other supporting structures. Calculation of self weight and live load is specified by the MSZ ENV 1991-2-1:1999 standard in Hungary [7]. In a general form, strain by self weight and live load is the following:

$$F_M = G\gamma_1 + F_h\gamma_2$$

where G is the load of the structure, F_h is the live load, and γ_1 and γ_2 are safety factors. The safety factor of the self weight (γ_1) is between 1.1 and 1.3, the safety factor of the live load (γ_2) is between 1.2 and 1.4.

Meteorological loads

At wrought iron structures, wind action and snow loads have to be taken into account among meteorological loads.

- Snow load has an effect on structures that have extensive horizontal surfaces or serve as support of these structures (e.g. cantilevers of balconies and corridors). Snow load should be counted by the MSZ ENV 1991-2-3:1999 standard [3; 7]. The characteristic value of snow load in Hungary is:

  $$P_s = 0.8kN/m^2$$

  The safety coefficient in this case changes between 1.4 and 1.75 in accordance with the self weight of the roof.

- Wind load has an effect on nearly every wrought iron structure in the open air. The calculation of the characteristic value of wind action according to the MSZ ENV 1991-2-4:1999 Hungarian standard is the following:

  $$p_w = w_0 * c$$

where w_0 is the stagnation pressure and c is the shape factor. [3; 7] Wrought iron structures are usually lattice-works, which are calculated with the shape factor (c) of $1.2 - 1.4$, in accordace with the cross-section of lattice-rods. It is necessary to mention that most wrought iron lattice-works are different compared to a general lattice. It is presumable that the use of a more specific shape factor would yield better results. This supposition can be proved only experimentally. Experiments are also needed for the calculation of a more precise shape factor.

Dynamic, variable and special loads

Certain wrought iron structures (e.g. during opening and closing the gates) are exposed to dynamic loads that should be considered by calculations.

There are some special effects as well (e.g. the load of a slamming door on the hinges, or the weight of a climbing body on the fence). These can be counted only by some supposition due to great variability.

5.2.2 The static model

As wrought iron structures are complicated, it is advisable to use an approximate static model for strength calculation. The mounting points of the structure can be the joints of the model that can be connected with imaginary lines. This static model is approximate only, but the calculation is much easier this way. The connections can be joints or rigid ones. In most cases, collaring, mortising, and riveting can be considered as articulated connections. Rigid connections can be made, for example, with an external strengthening element at the corner.

As regards the external supports of wrought iron structures, we can make a distinction between joint, restrained, and moveable support types. Moveable support is, for example, if the work is simply placed on the floor; joint support can be a screwed connection or an overhung; while restrained support is, for example, the fixation of a railing into the concrete floor [3].

6 SUMMARY

Smithcraft has a significant history; it played a very important role in many periods of the past. In the present, wrought iron techniques are used in two main fields, namely in the fields of monument restoration and in the fields of applied art. The examination of the material (steel) qualities in case of historical constructions and the observation of the static behavour of the wrought iron structures can help restoration in the first and design in second case. We need, however, further experiments for these.

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