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PROCESSES

Investigation of the altered influence of physical stress by the use of ergonomically optimized forging tongs

David Schellenberg[1] · Mareile Kriwall[1] · Malte Stonis[1] · Bernd-Arno Behrens[1,2]

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Abstract
Work-related illnesses and the resulting employee absences can have a major impact on productivity and competitiveness, especially in small and medium-sized enterprises. Particularly in the forging industry, the manual handling of forged parts leads to high physical stress and thus to frequent illnesses of the musculoskeletal system, especially of the hand-arm system. One possibility to counteract this circumstance is the use of ergonomic forging tongs. In the study presented here, the influence of ergonomic forging tongs on the physical stress of forging employees was investigated by simulation and experiment and compared to conventional forging tongs. Within the simulation and the experimental investigation, forging parts and forging tongs were varied. In the simulation, an ergonomics assessment of the forging situation could be evaluated using the Ergonomic Assessment Worksheet. In the experimental study, gripping force measurements and calorie measurements were used to determine the impact of handling the forging tongs on the forging employees. The results show that the use of the new ergonomically optimized forging tongs can lead to a significant physical relief for the forging employees. The knowledge gained from the ergonomically developed concepts can also be transferred in other industries.

Keywords Forging · Forging tongs · Physical stress · Ergonomic

1 Introduction

Diseases of the musculoskeletal system are among the most frequently occurring diagnoses of incapacity to work. A comparison of the individual sectors of the economy shows that metalworking, including forging, is one of the most affected sectors by this problem [1]. Due to the physical stresses caused by the manual handling of forging tongs and forged parts, musculoskeletal disorders are among the most common diagnoses in forging companies [2].

A possible way to protect forging employees from the physical stresses they encounter is to use ergonomically optimized forging tongs. These can facilitate the handling of forged parts in the individual work steps and protect the forging employees from overload. Within the research project “Development of ergonomically optimized forging tongs for power-assisted and vibration-damped handling of forged parts (ErgoZang)”, different forging tong concepts were developed and prototyped. The purpose of this study was to compare the developed ergonomic forging tongs concepts with conventional forging tongs. A possibility to compare the concepts under different conditions was provided by stress evaluation procedures. Three stress evaluations were carried out within this study. Each stress evaluation involved a different aspect. As a result, the three stress evaluations complement each other and allowed an overall assessment of the physical stress.

The first possibility to evaluate the physical stress is to measure the gripping force. By examining the gripping force which is required for handling the forging tongs, it is possible to evaluate the force the forging employees apply to the forging tongs. The larger the required gripping force, the greater the physical stress on the forging employees.

The second possibility of physical stress evaluation involves the virtual ergonomics assessment. The virtual ergonomics assessment is carried out using the EMA WORK-DESIGNER software. A simple work sequence in hammer

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✉ David Schellenberg
schellenberg@iph-hannover.de

[1] IPH - Institut für Integrierte Produktion Hannover gemeinnützige GmbH, Hollerithallee 6, 30419 Hannover, Germany

[2] Institute of Forming Technology and Machines (IFUM), Leibniz Universität Hannover, An der Universität 2, 30823 Garbsen, Germany

forging, as found in many forging companies, served as a basis. This work sequence was simulated in the ema WorkDesigner and evaluated by means of the Ergonomic Assessment Worksheet (EAWS).

The third possibility of the physical stress evaluation is the calorie measurement of a person during the forging process. The calorie measurement was carried out using the Sensewear measurement system from Bodymedia. The execution of the work sequence corresponded to the parameters from the simulation. The aim of this study was to be able to provide a detailed statement during the overall stress influence on the human body during the work and the influence of the different forging tongs.

1.1 Manual hot forging

In particular, in small and medium-sized enterprises in the forging industry, with a low degree of automation and high production flexibility, many forging operations are still involve manual handling of forged parts by using forging tongs. Although other manual operations are also carried out for the production of forged parts, only forging operations that are performed with the aid of forging tongs were considered for this study. In Fig. 1 the operations which are involved in forging processes are shown. Basically, the forging process can be divided into *forging* and *conveying* steps. In *forging* a workpiece is formed into a forged part. In conveying, a distinction is made as to whether the forged part is only transported or whether it has to be picked up thereby involving more complex handling with forging tongs.

While working with forging tongs, the hands and fingers, in particular, have to exert a large force. This force is primarily finger static and occurs in the contact area between the hands and the forging tong handle. Finger static means that the movement of the forging tongs is mainly done through the body and not through the movement of the hands or fingers [3]. There are two options when guiding forging tongs. In Fig. 2 the two possible grip types according to Kern et al. [3] are shown.

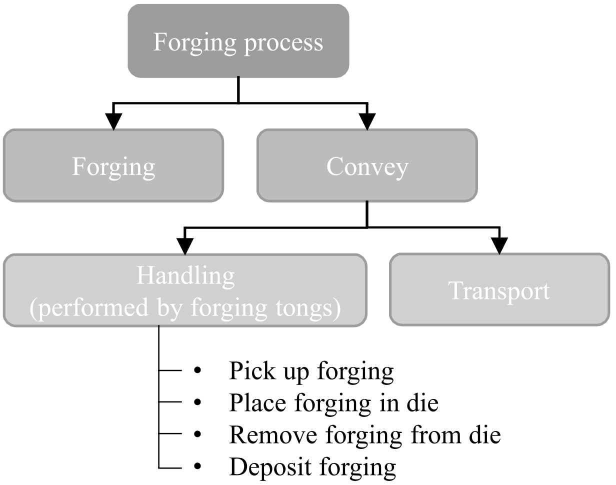

Fig. 1 Handling operations during forging according to Kern et al. [3]

For a conventional, two-handed grip, each leg of the forging tongs is gripped individually. This is particularly necessary when larger forged parts are involved. However, there is also the variant of placing one hand directly behind the joint as an abutment. This variant facilitates the handling of the forging tongs and the transport of forged parts [3].

Depending on the various handling processes, different physical stresses act on the musculoskeletal system. In general, handling and transporting forged parts leads to stresses on the musculoskeletal system [4]. Transporting the forged parts with the forging tongs generates high moments, which thus place considerable stress on the hand-arm system [5].

Additional stresses are caused by the ambient conditions in forging companies, where high temperatures, air pollution and noise are important factors. The high forging temperatures of up to 1250 °C and the resulting high ambient temperatures create stressful working conditions with combustion potential [6].

1.2 Structure and function of forging tongs

The currently used conventional forging tongs and the developed ergonomically forging tongs are explained below. All forging tongs that were tested have the same weight of approx. 2 kg and a length of approx. 600 mm.

Conventional forging tongs: The purpose of the conventional forging tongs is to enable the manual handling of forged parts, of varying temperature, mass and shape. In Fig. 3 some conventional forging tongs are shown.

Forging tongs consist of two metal parts connected with a joint. The gripper jaw (1) can have various forms, and is adapted to the respective parts that shall be handled with the forging tong. Via the joint (2), the components of the forging tongs are connected with a rivet pin to each other. The forging tongs legs (3) transmit the force applied by the forging employee, which is required to hold the forged parts in the jaws.

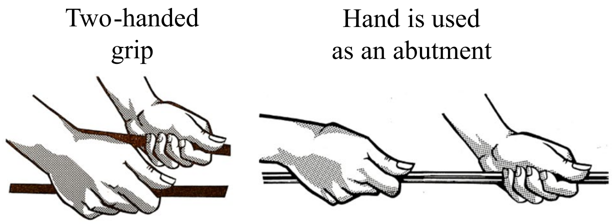

Fig. 2 Types of grip used during forging according to Kern et al. [3]

Fig. 3 Structure of some conventional forging tongs

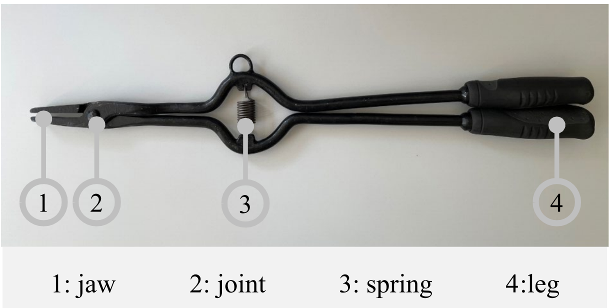

Fig. 4 Structure of some tension spring forging tongs

Fig. 5 Structure of some knee-joint forging tongs

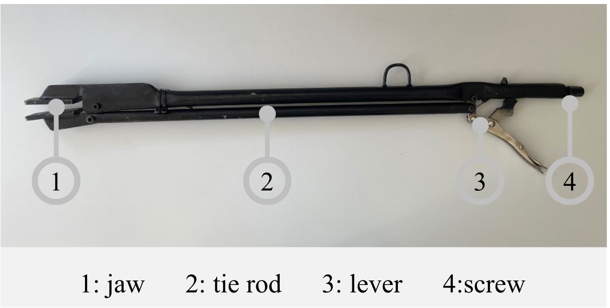

Fig. 6 Structure of some grip forging tongs

Tension spring forging tongs: Tension spring forging tongs are one of various ergonomic forging tongs. The tension spring forging tongs differ from conventional forging tongs mainly due to the connection of the two forging tong legs by a tension spring. Depending on the forging process they can be used with both grip types. In Fig. 4 some spring forging tongs are shown.

The spring (3) has the function of keeping the two forging tong legs (4) closed. By pulling the two legs apart at the handles (4), the jaw (1) is opened and the forging can be picked up. After a reduction in the force with which the legs are pulled apart, the tong legs are closed again by the spring force and the forging is held in place. The use of the spring reduces the force required to hold the forged part.

Knee-joint forging tongs: Knee-joint forging tongs are one of various ergonomic forging tongs and can be used with both grip types. In Fig. 5 the structure is shown of some knee-joint forging tongs.

The difference to conventional forging tongs is the use of a slide with a knee-joint (2). The slide with a knee-joint allows the jaw opening (1) to be varied, thus enabling individual adaptation to different forging part geometries. This improves the transmission ratio between the jaw and the legs (3) and thus enables improved force application and hand position.

Grip forging tongs: Grip forging tongs are one of various ergonomic forging tongs. With the grip forging tongs, the forging tongs jaw movement is performed by one hand. This enables the forge employee to use the other hand as an abutment and to minimize the resulting moments on the hand-arm system due to the forging tongs and the additional forging part. The design of this is shown in Fig. 6.

The lever (3) applies the force to close the jaw (1). The lever is connected to a tie rod (2), which ensures the transmission of force between the handle and jaw. The tie rod can be screwed in at different depths by means of an adjusting screw (4), which allows the distance between the jaws to be varied. This facilitates adaptation to different forged parts and additionally an improved transmission between lever movement and force application in the jaw.

Support Frame: In addition to the ergonomically developed forging tongs, another ergonomic aid was developed, the support frame. The support frame is a modification of a backpack and can be combined with forging tongs. The carrying frame consists of a backpack system including a back vest, pelvic belt, balancer and a carrying arm for attachment to the forging tongs. This allows the weight related force of the forging tongs and the forging parts to be distributed over a large area of the body and be balanced out. In accordance with ISO 6385, the support frame was designed in such a way that several more powerful muscles in the back can be used [7]. This makes it possible to guide the forged parts, thereby reducing the stress on the hand and arm in particular (Fig. 7).

Fig. 7 Support frame for facilitated guidance of forged parts

2 Examination methods

In the following, the investigation methods used for evaluating the stress influence of ergonomic forging tongs are explained. For this, the selection of the forging parts, the gripping force measurement, the virtual ergonomics evaluation and the calorie measurement are described.

2.1 Selection of the forged parts

For the investigations, a selection of a forging process was made. The selection of forged parts is essential for the forging process and the resulting influence on the physical stress. The selection of forged parts was done according to Spies [8]. The selected forging classes can be divided into class 1 (compact forged part) and class 3 (long forged part) (see Fig. 8) and are the most common shapes [9]. The investigation of the forging shape is relevant since it can be assumed that the mechanical moments that occur are amplified and increased by long parts, and thus also the gripping forces required to hold the forged parts securely in the forging tongs jaws. In order to be able to make a statement on the effect of the shape, the investigations were carried out for long and compact parts. The selection of weights, 2.5 kg and 5.7 kg, represents a wide range of forged parts used in a typical forge and the institute [10, 11]

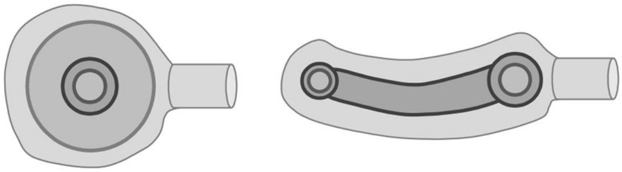

Fig. 8 Examples of the considered forged parts (left: compact forged part; right: long forged part)

2.2 Gripping force measurement

A gripping force measurement is needed in order to evaluate the forces between the hand and the forging tongs. The finger-static gripping force measurement can be used to show that there is a stress for the forging workers when the measured values are compared with occupational safety recommendations.

For gripping force, maximum gripping forces of 500 N (men) and 350 N (women) and maximum compressive forces on a thigh with an outstretched arm of 55 N (men) and 35 N (women) are recommended for short-term exertions [12]. For repetitive intense activities such as forging, only about 10% of the maximum force should be applied, resulting in optimal target values of 50 N (men) and 35 N (women) for gripping force and of 5.5 N (men) and 3.5 N (women) for compressive force [12].

In order to measure the gripping force applied to the forging tong, a hand dynamometer was placed under the forging tongs. This hand-dynamometer consists of strain gauges which record the forces or moments acting from outside.

Within the examination, the forged part was held and lifted with the forging tongs for a few seconds. Then the gripping force was removed. The acting maximum gripping force was shown on the display of the hand-dynamometer.

Measurements were also made for the grip type with the hand as an abutment, since this is the most common grip used in the forge. The measurement was performed for both hands (see Fig. 9). The investigation was carried out with the forged parts selected in Chapter 2.1.

The measurement was performed using the following parameters:

- Forging tongs: Conventional forging tongs, tension spring forging tongs, knee-joint forging tongs, grip forging tongs, grip forging tongs with support frame.
- Gripping Area:Front, back.
- Compact forged parts: 2.5 kg and 5.7 kg.

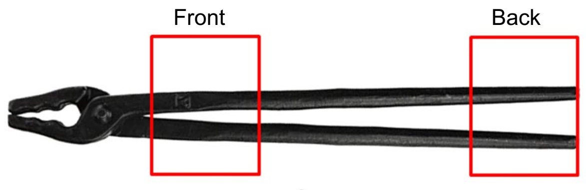

Fig. 9 Measured grip areas using the example of conventional forging tongs

- Long forged parts: 2.5 kg and 5.7 kg.

2.3 Ergonomic assessment of a simulated forging process

A virtual ergonomics assessment was used to obtain an understanding of the ergonomics of the process by using standardized procedures and thus to provide an indication of the degree of stress. For the ergonomics assessment, the EAWS method was used. The EAWS is an assessment method designed to rank and evaluate ergonomic risks in industrial environments. The total stress for the forging employees is composed of the evaluation of several different types of stress. The evaluation focuses on the overall physical risk areas such as posture, action forces and load handling. In addition, special risk areas, such as those involving the upper body extremities and also activities with high repetitive accuracy, are evaluated. An analysis of the influencing factors is performed for each risk area, whereby the force exerted, the body posture and the duration of the stress are taken into account. The resulting score describes the risk of physical stress. The higher the numerical value, the higher the risk for the assessed activity.

In order to be able to create a virtual ergonomics assessment, a simulation was set up within the EMA WorkDesigner software. A method was used which followed the general procedure of simulations according to VDI – 3633 [13]. This was divided into three phases:

1. Preparation: In this phase, the input for the simulation model was defined and the system behavior of the real system was analyzed and modelled.
2. Execution: In this phase, experiments were subsequently carried out with the simulation model
3. Evaluation: The experimentally obtained results were formulated and evaluated. This involved validating the simulation model and deriving conclusions, solutions and possible modifications for the real system.

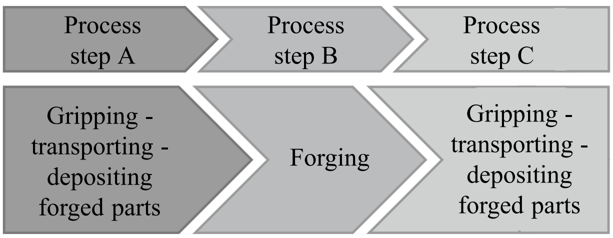

Fig. 10 Process steps within the virtual ergonomics assessment

In the first phase, the input for the simulation system was the setup of a forging workplace, in which the focus is primarily on the manual handling of forging tongs. The handling processes of forging and conveying (see Chapter 1.1) are considered.

In order to be able to represent as many relevant process steps and stresses as possible a simple forming process with an prototypical forging hammer was considered. In addition, the transport processes to and from the forging hammer were considered. The process steps with the handling operations are shown in Fig. 10.

In addition to the influence of the forging tongs from Chapter 1.2, the influence of the forging parts from Chapter 2.1 on the ergonomics was investigated. Since the developed ergonomic forging tongs are not included as standard tools within the database of the EMA WorkDesigner software, the results of the gripping force investigation had to be integrated into the simulation. With the help of the gripping force parameters in the simulation, the individual forging tongs were compared in terms of an ergonomics assessment.

Within the simulative investigation, the anthropometric data were not varied. In accordance with DIN 33,402, the 50th percentile was used as the human model.

In the second phase the simulations were carried out under variation of different parameters (forged parts, forging tongs). The experimental setup followed the basic steps as shown in Fig. 10.

The gripping or laying down of the forged part was implemented in the form of worktables (i) (Fig. 11, upper). Since no forming machines are available in EMA WorkDesigner and forming processes cannot be represented, an object file (ii) from a CAD database was inserted, which is modelled on a forging hammer. The forces and vibrations occurring during the forming process were represented by the behavior function. The simulated test person (iii) carried out the individual process steps. When performing process steps A-C, the test person went through the following procedure.

Before process steps A-C were performed, the forging tongs must first be picked up (0) (see Fig. 11, lower). Process step A starts with picking up the workpiece (1) and ends at the forging hammer (2). When the forming in process step B has been completed, the forged part and the forging

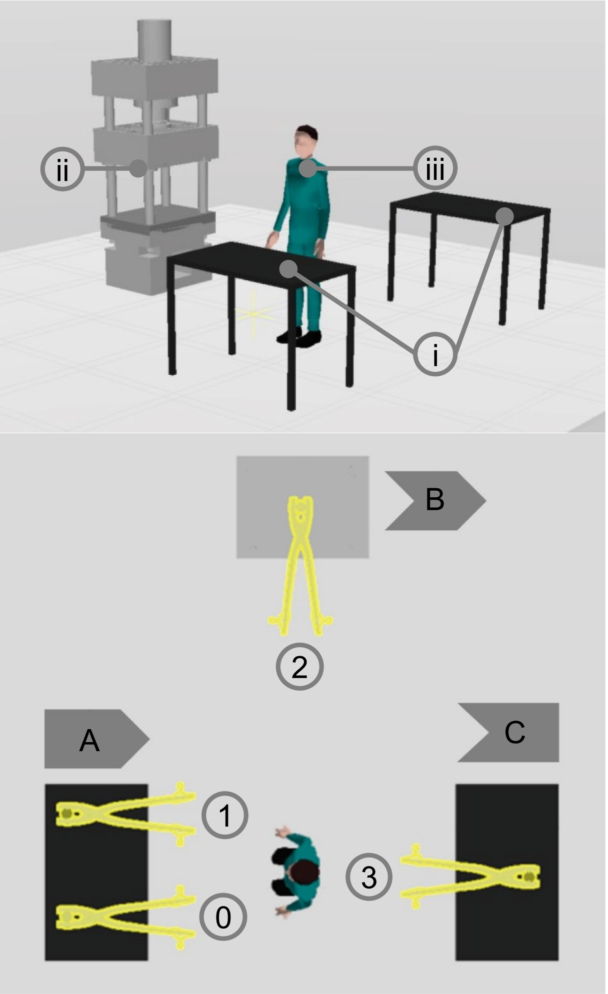

Fig. 11 Structure of the test forge in EMA WORKDESIGNER

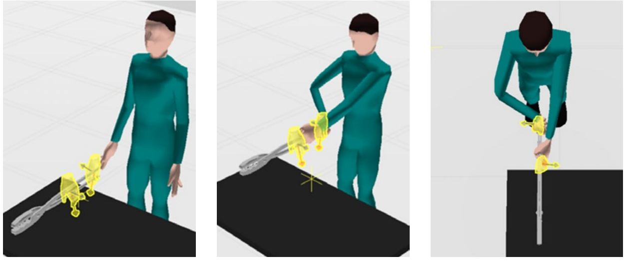

Fig. 12 Setting the markers for gripping the forging tongs (left), gripping the forging tongs (middle and right)

Table 1 Traffic light scheme in accordance with EN 614–1 [14]

Point range	Evaluation		Necessary measures
0 – 10 points	🟩	Green	Low risk: recommendable; measures not required
> 10 – 25 points	🟩	Green	Low risk: recommendable; measures not required Possible risk for certain groups of people (e.g., performance-modified people). Review measures for redesign
> 25 – 50 points	🟨	Yellow	Possible risk: not recommendable; take measures to redesign
> 50 points	🟥	Red	High risk: avoid; risk control measures required.

tongs were carried to process step C for laying down at the worktable (3).

The next step was to define how the human model should grip the forging tongs. Two aspects were taken into account. The hand position and, based on this, the type of grip. In order to be able to define the position at which the hands should grip the tongs, markers have been used in the EMA WORKDESIGNER. These were applied for both hands as a child object under the forging tongs and then positioned on them. In Fig. 12 the positioned and aligned markers are shown when gripping the forging tongs with one hand as an abutment.

With this setup, simulative tests were performed with the following parameters:

- Forging tongs: Conventional forging tongs, tension spring forging tongs, knee-joint forging tongs, grip forging tongs
- Compact forged parts: 2.5 kg and 5.7 kg
- Long forged parts: 2.5 kg and 5.7 kg

In the third phase, all measured values were presented and compared in the form of EAWS points. The differences between the individual point values for the respective forging tongs concept were compared to the case for conventional forging tongs.

Finally, the determined EAWS point values were classified in a traffic light scheme based on EN 614–1 (Table 1) [14].

2.4 Calorie measurement

A calorie measurement is suitable for recording the degree of physical stress on the forging employee. The higher the physical stress, the higher the calorie requirement. However, since the calorie requirement varies depending on the activity, the metabolic equivalent (MET) value is often chosen as an additional comparative value. The MET value depends on the energy consumption. A MET value of 1 corresponds to an average oxygen uptake of 3.5 ml O_2-kg^{-1}-min^{-1} or 1 kcal-kg^{-1}-h^{-1}. This is the average oxygen uptake of an adult person at rest. The MET value is unitless. Light physical activities correspond to a MET value < 3. Moderate physical activities correspond to a MET value between 3 and 6. For heavy work, the MET value corresponds to over 6 [15]. For forging activities, the associated MET value should be as low as possible. In consultation with forging companies, it was decided that a value of 4 should not be exceeded.

The Bodymedia SenseWear was used to measure the calorie consumption during the performance of the forging tests. With this multisensory activity monitor investigation of the physical activity was possible [16]. In Fig. 13 the used Bodymedia SenseWear is shown.

It consists of the following three sensors: accelerometer (3-axis), heat production and skin conductivity [18]. From the obtained sensor data the Bodymedia SenseWear software can be used to evaluate the calorie requirement and MET value.

The wristband was worn on the upper third of the left upper arm. The wristband had to be clean and free of chemicals, such as cream or oil. The bottom of the SenseWear had to rest exactly on the skin. There was room for two fingers under the worn wristband [17].

The same setup as in the simulation environment (see Fig. 10) was chosen. However, only tests with the compact forged parts were carried out and evaluated, the following parameters were varied:

- Forging tongs: Conventional forging tongs, tension spring forging tongs, knee-joint forging tongs, grip forging tongs, gripping forging tongs with support frame
- Compact forged parts: 2.5 kg and 5.7 kg

Fig. 13 Bodywear Sensewear [17]

3 Results and discussion

3.1 Result of the gripping force measurement

The measure of gripping forces for the front hand and the back hand per forging, and for the respective forging tongs and the supporting frame are shown in Figs. 14 and 15. The following conclusions can be drawn from the results displayed in the diagrams.

The gripping force at the front is only reduced to a limited extent by the use of the ergonomic forging tongs. For example, the gripping force required to handle a 5.7 kg long forged part reduced from 179 N with conventional tongs to 159 N with grip forging tongs (Fig. 14). This small reduction in the gripping force of approx. 11% is due to the fact that the front hand has to absorb the weight load, including the moment that occurs, and thus hardly any relief can be achieved. The front hand can only be relieved by using a support frame. For example, the gripping force required for the conventional forging tongs with a long forged parts of 5.7 kg

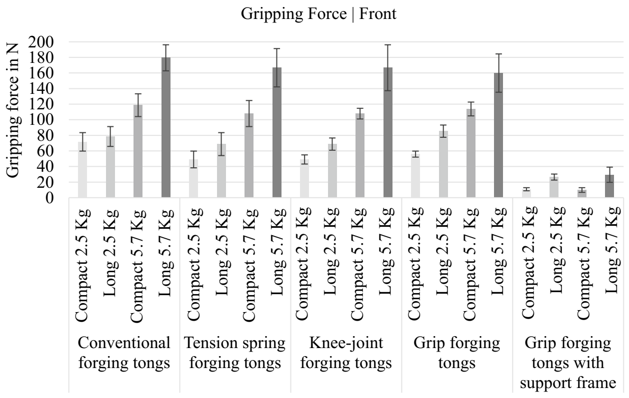

Fig. 14 Measured gripping forces in the gripping area at the front [17]

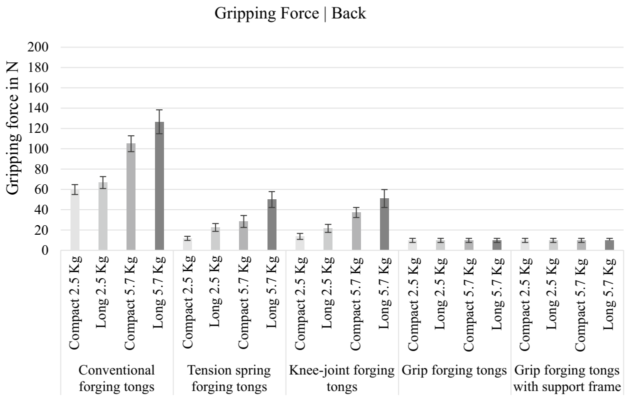

Fig. 15 Measured gripping forces in the gripping area at the back

reduced from 179 N to approx. 29 N when using the grip forging tongs with a support frame. This is a reduction of up to 83%. This high reduction occurs due to the support frame that can be coupled with the front area of the forging tongs, thereby allowing the stress to be removed from the front hand. As assumed in Chapter 2.1 the weights and shapes of the forged parts have an influence on the gripping force. For example, heavier forged parts require a higher gripping force than lighter forged parts. Long forged parts also require higher gripping forces than compact forged parts.

If the gripping forces of the rear hand are considered, it is clear that the ergonomic forging tongs have a large influence on the gripping force (Fig. 15). For example, the gripping force of conventional forging tongs for a long forged part of 5.7 kg was reduced from 126 to 50 N by using tension spring forging tongs, to 51 N by using knee-joint forging tongs and to approx. 9.8 N by using grip forging tongs.

The rear hand is responsible for holding the forging tongs closed. By relieving the weight through the use of the support frame, the gripping force applied to the forging tongs can be reduced. Due to the gripping force of the tension spring forging tongs, a lower gripping force is required. In addition, the increased force transmission with the knee-joint forging tongs, requires there to be a lower gripping force. The fact that the grip forging tongs can firmly clamp the forged part means that no gripping force is required to hold the forging tongs closed, which is why the gripping force is lowest for this case.

Only by the use of the combined solution consisting of the support frame and grip forging tongs were the target values of 50 N for the gripping forces undercut.

3.2 Result of the simulation of a forging process

Within the simulation, the forging tongs were varied. Due to the software, it is not possible to consider a support frame. Simulative handling was performed for compact and long forged parts weighing 2.5 kg and 5.7 kg.

The results shown in Table 2, reveal that the conventional forging tongs tend to score higher (47.5 for a 2.5 kg compact forged part and 96.5 for a 5.7 kg long forged part) than the ergonomic forging tongs (e.g., grip tongs with a score of 40 for a 2.5 kg compact forged part and 58 for a 5.7 kg long forged part). Significant differences between the ergonomic forging tongs did not occur. There is a tendency for the grip forging tongs to result in lower ratings than the other forging tongs. However, all ergonomic forging tongs lowered the EAWS value compared to the conventional forging tongs and thus partially reached a yellow rating of the traffic light scheme. Based on the results of the gripping force measurements, it would be reasonable to expect that more significant reductions in the EAWS values could have been achieved in the simulation if the support frame had been used. By using the EAWS no detailed differences between the forging tongs can be identified.

Table 2 Ergonomics evaluation of the ergonomic forging tongs based on the EAWS

Forging tongs	Forged parts			
	Compact		Long	
	2.5 kg	5.7 kg	2.5 kg	5.7 kg
Conventional forging tongs	47.5	71	51.5	96.5
Tensile spring forging tongs	41	51	47	68.5
Knee-joint forging tongs	40	53	46	68.5
Grip forging tongs	40	48	45	58

3.3 Result of the calorie measurement

In Fig. 16 the measured calorie consumption during the forging tests is shown. A forging test consisted of 60 forging operations in which steps A-C were performed within approximately 15 min. Each column shown represents the calorie average consumed for one forging operation. In addition to the studies using forging tongs and the forged parts, caloric studies were also performed for the baseline stress without any additional stress (walking and standing). Shown in the figure are the results for handling with a 2.5 kg and 5.7 kg compact forging.

From the tests, it could be determined that when considering the calorie consumption for a 5.7 kg forged part, the support frame in combination with the grip forging tongs (6.8 kJ) allowed a calorie reduction of up to 47% compared to conventional forging tongs (12.9 kJ). In addition, a higher forging part weight leads to a higher calorie consumption. The higher calorie consumption was slightly reduced by ergonomically optimized tong concepts (conventional forging tongs: 12.9 kJ; tension spring forging tongs:

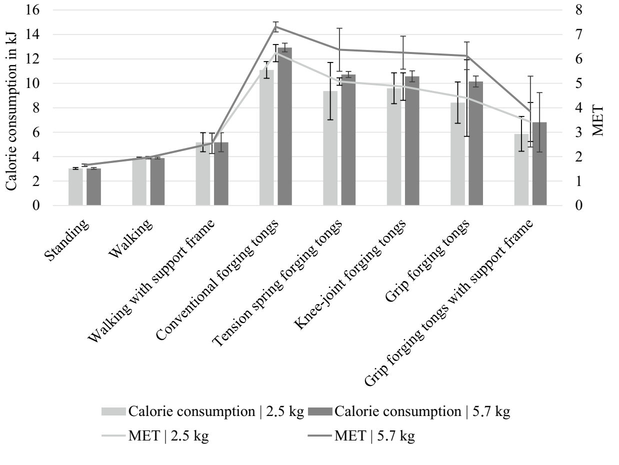

Fig. 16 Results of calorie measurement with compact forged parts 2.5 kg and 5.7 kg

10.7 kJ; knee-joint forging tongs: 10.6 kJ; grip forging tongs: 10.2 kJ). Only by using a support frame, to relieve the hand-arm system by redirecting the weight forces to the back, was an increased reduction in the calorie consumption achieved. The MET value varies between 1.9 (for standing) and 7.3 (for forging with conventional forging tongs).

Overall, for the forging operations, the grip forging tongs (especially in combination with the carrying frame) led to the lowest calorie consumption.

Only using a carrying frame with the grip tongs could MET values below 4 be reached. However, the results are very individual to the person. The test person was not a skilled forging employee, which might lead to higher calorie consumption compared to a skilled forging employee.

4 Summary and outlook

Within this study, the physical stress during manual forging was evaluated. For this purpose, the stress during manual handling with conventional and ergonomically optimized forging tongs (tension spring forging tongs, knee-joint forging tongs, grip forging tongs and grip forging tongs with support frame) was evaluated using four selected forged parts as examples in a test environment. The evaluation of the stress was performed using three evaluation methods. The grip force measurement method was used to determine the finger static grip forces and the transferred force between the hand and the forging tongs. This showed that the conventional tongs require up to 83% higher gripping forces than, for example, the grip forging tongs with support frame. The second method, the virtual ergonomics evaluation based on the EAWS, was carried out using the EMA WORKDESIGNER simulation software. Since the EAWS method is a global ergonomics value, no significant differences between the ergonomic forging tongs could be evaluated. Nevertheless, the use of ergonomically optimized forging tongs led to slightly lower EAWS values than the conventional forging tongs. The ergonomic forging tongs investigated did not result in an EAWS value below 25 within the traffic light scheme, so that further additional ergonomic measures are necessary. Within the software it was not possible to implement the support frame. It can be assumed that support with the support frame would lead to a significant relief of the hand-arm system and the upper extremities, and, therefore, the EAWS value would be in an acceptable range. For an analysis involving this, a way would have to be found to incorporate the support frame within the simulation.

The third test method, calorie measurement, was used to evaluate the degree of stress caused by manual handling. By using a calorie measurement system, the stress was measured while handling compact forged parts and a MET value was detected. Within the investigation it could be shown that, for example, grip forging tongs with a support frame could reduce the calorie consumption by up to 47% compared to conventional forging tongs. In future investigations, the stress must also be verified using long forged parts. The handling of long forged parts is expected to result in higher stresses, thereby increasing the potential for stress reduction by the use of ergonomic forging tongs.

The comparison of the ergonomic forging tongs showed that the grip forging tongs in combination with the support frame had the highest potential for reducing the stress. The reason for this is the firm clamping of the forging parts without the necessity for an additional gripping force and the transfer of the weight load to the whole body. The knee-joint forging tongs and the tension spring forging tongs also show a stress reduction potential compared to the conventional forging tongs, but the reduction potentials were similar between them.

The results show that the use of ergonomically optimized forging tongs can reduce physical stress. The potential was shown for ergonomic optimization to have a significant impact on physical stress. It is expected that the use of such ergonomic tools will also contribute to higher employee satisfaction. The knowledge gained from the concepts of the ergonomic forging tongs can also be transferred to other areas in industry where high loads act on employees and high gripping forces are required. Some examples of these industries would be tanneries, automotive body shop or roofing and plumbing.

In the future, it will be necessary to investigate the service life of the ergonomic forging tongs and how long-term studies show the stress-relief over time.

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Declaration

Conflict of interest The authors declare that they have no conflict of interest.

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