APEM journal
Advances in Production Engineering & Management
Volume 17 | Number 3 | September 2022 | pp 339–349
https://doi.org/10.14743/apem2022.3.440
ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

Experimental determination of influences on a gauge block's stack length

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ABSTRACT

Gauge blocks are an important basis for maintaining traceability in dimensional metrology, used for calibrating length measuring instruments and for adjustments in all branches of manufacturing. Their important feature is that they can be wrung with small dimensional uncertainty. An overview of the factors influencing the accuracy of a stack length, such as the quality of the gauge blocks (grade, wear), surface preparation (cleaning and usage of a lubricant), wringing (way and time, temperature of hands and gloves) is given in the paper. Experiments for determining these influences were performed with a highly precise gauge block comparator. Proper selection of gauge blocks, preparation of their surfaces and oiling improve the accuracy of a stack length. Application of a lubricant, wiped with a dry cloth or paper towel, helps to wring them more easily, but its contribution to the stack length in the experiment was 0.1 µm for oil and 0.2 µm for grease. Temperature changes of gauge blocks were estimated by holding them, and, during wringing in well controlled air conditions, monitoring them to yield the empirical coefficients of their warming up. The results showed that usage of gloves reduces the warming up by approximately half, but still the stack must be stabilised in well controlled conditions for at least one hour if it is used for micrometre-level precise measurements.

ARTICLE INFO

Keywords:
Gauge blocks;
Wringing;
Measurement uncertainty;
Dimensional metrology

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Article history:
Received 7 April 2022
Revised 25 September 2022
Accepted 28 September 2022

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1. Introduction

Gauge blocks (GBs) are one of the most accurate standards of length, an important basis of industrial length measurements, as well as commonly used measurement standards for maintaining traceability in dimensional metrology. They are made of wear-resistant material (hardened steel, ceramics, or tungsten carbide), and their length is defined by two parallel measuring surfaces. An important feature of gauge blocks is that they can be joined together with very little dimensional uncertainty. They are used as a reference, either as single blocks, or two or more joined strongly together by wringing, or wrung onto plates with a similar high-quality surface.

The four grades of GBs available on the market are defined by the Standard SIST EN ISO 3650. The reference standard sets of grade K are calibrated by laser interferometry, performed almost exclusively by national laboratories. Lower-level grade sets are calibrated by mechanical comparison to the reference GBs, performed widely in calibration laboratories throughout the engineering industry. Calibration uncertainty with a comparator is inferior to interferometric calibration, but the instrumentation is less expensive and the procedure much simpler. Generally, GBs of grade zero are used for inspections and calibrations in measurement laboratories, GBs of grade 1 are used for precise adjustments, e.g., for sin bars, GBs of grade 2, having the smallest accuracy, are used for adjusting machine tools.

In micrometre-precise laboratory and production measurements, grade zero is generally used as a reference. Along with length deviation and the uncertainty of GBs, known from their calibration certificate, the uncertainty of wringing film thickness and thermal contributions to the mutual uncertainty of the reference, must be taken into consideration. In the present paper, these uncertainty contributions are analysed and presented by in-situ measurements of different GBs (ceramic, steel; single or wrung), performed with a gauge block comparator and precise temperature sensors in well controlled air conditions.

The experiments were performed in the Laboratory for Production Measurement (University of Maribor, Slovenia). The applied mechanical comparison procedure is accredited, and the calibration and measurement capability (CMC) is included into the key comparison database at BIPM [1, 2]. The laboratory, as a holder of the National Standard for length, is accredited for length-calibrations of standards and measuring equipment, with the primary purpose to assure dimensional traceability in Slovenian industry. For maintaining high level measurement capability, the laboratory develops measurement procedures steadily with novel equipment and laser interferometry, and, periodically, joins international comparisons for their verification [3-6]. Reliable measurement systems are especially important in complex geometrical measurements, as well as in precise machine tool monitoring and verification, in the sense of optimising production processes, and for controlling product quality. The secondary task of the laboratory is focused on the development of sustainable manufacturing systems and advanced automated integration of data, including calibration results, up to the global information level [7, 8].

2. Materials, methods and execution of expaeriments

2.1 Gauge blocks as a length standard

Standard SIST EN ISO 3650 defines the geometrical characteristics of gauge blocks and tolerances precisely for four grades, at the standard temperature 20 °C. Some are represented here (Fig. 1 and Table 1) for the purpose of interpretation of the experimental results. The limit deviation, t_e, is the maximal permitted deviation of the length from the nominal length l_n at any point of the measuring face. The recommended points to measure are the five points presented in Fig. 1. The tolerance t_v is defined for variation $v = l_{max} - l_{min}$. The central deviation is $e_c = l_c - l_n$, while the limit deviations are defined as $f_o = l_{max} - l_c$ and $f_u = l_c - l_{min}$.

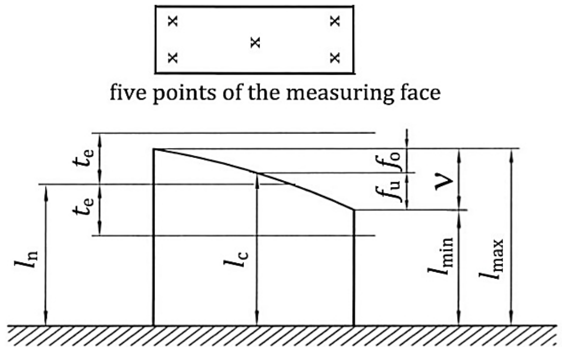


Fig. 1 Geometrical characteristics of GB length

Table 1 Limit deviation, t_e, of the length at any point of the measuring face from the nominal length and tolerance, t_v, for the variation in length

	Grade K		Grade 0		Grade 1		Grade 2	
L_n / mm	t_e / µm	t_v / µm	t_e / µm	t_v / µm	t_e / µm	t_v / µm	t_e / µm	t_v / µm
$0.5 \leq L_n \leq 10$	0.2	0.05	0.12	0.1	0.2	0.16	0.45	0.3
$10 < L_n \leq 25$	0.3	0.05	0.14	0.1	0.3	0.16	0.6	0.3
$25 < L_n \leq 50$	0.4	0.06	0.20	0.1	0.4	0.18	0.8	0.3
$50 < L_n \leq 75$	0.5	0.06	0.25	0.12	0.5	0.18	1.0	0.35

Although the materials chosen for producing GBs have very stable crystal structures, on the level of the required reliability (of grade K and 0) the material structure stability is still temporal, even with proper handling and storage. Therefore, periodical calibration of GB sets is recommended, once per year up to three years, depending on the frequency and required dimensional accuracy of their use. The measuring surfaces are polished to such a degree that can be joined easily by sliding, and they can get so strongly adhered that can be separated only by tangential pulling apart. The wringing film is small, with very little dimensional uncertainty, if the gauge blocks are treated properly. Considering the fact that GBs are used either as a single block wrung onto a plate with similar surface quality, or as a stack of blocks, the wringing film is included into the calibration results of the block length, as defined by the ISO 3650 standard (Fig. 1 and Table 1). In the case of calibrating Grade K with laser interferometry, the wringing film on the plate contributes to a length uncertainty of less than 6 nm [9]. The roughness of a well-polished surface varies from 15 nm to 30 nm [10, 11].

The wringing film thickness varies with the surface quality and lubricant fluid used. Blocks are cleaned with alcohol or petrol ether, while steel blocks also need protection against corrosion with special oil wetting. Before usage, the blocks are wiped with a lint-free cloth to make sure they are free from dust. By sliding the blocks air is squeezed out, and the surfaces get adhered together by vacuum and molecular interaction. The strong adherence can be explained by the surface tension of the liquid film (of oil, or water vapour from the air): The cohesive forces between molecules in a liquid and with a solid surface are stronger than those on its surface in contact with the air, therefore, when we try to separate the blocks, the liquid tries to minimise its surface. Fig. 2 presents the high ability of oil to wet the surface of a gauge block. Additionally, the fine roughness observed on the measuring surfaces could enhance the adhesion, due to the phenomenon of liquid bridge splitting, since mobile wetting bridges can naturally migrate to narrower gaps [12].

The stacks should be disassembled after usage, even in daily use. Leaving them together for a few days can cause that they become difficult to separate, or even to get permanently fused.

We need to make sure that the blocks to be wrung are clean, free from dust, nicks and burs. If the surface is not clean, for instance, due to fingerprints, they get wrung more easily, but the uncertainty of the wringing film is higher. The presence of nicks or burs was inspected visually and with an optical flat (Figs. 3a-c). We place the glass on the measuring surface of the block to check for a rainbow by sliding it slightly. If the rainbow disappears when we press harder, it means there are no asperities present. If the rainbow stays in the same place when we slide the glass over the block, it means that the asperity is on the block. If the rainbow moves, the asperity is attached to the glass surface, or too much oil was applied.

(a) A drop of oil wetted the measuring surface of the steel gauge block in 2 secs

(b) A drop of oil wetted the measuring surface of the ceramic gauge block in 3 secs

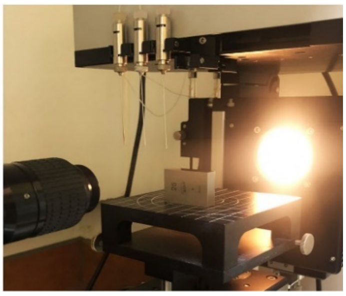


Fig. 2 Wetting of a GB surface with anti-corrosion oil (goniometrical observation of the contact angle)

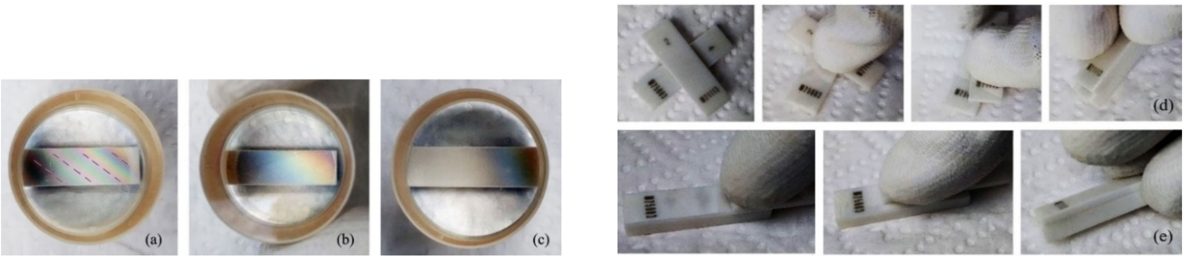


Fig. 3 The surface inspection with plane-parallel glass and wringing of thin blocks

Wringing should be done by sliding without much pressure. Two ways of wringing of thin blocks are presented in Fig. 3. By repeatedly sliding the upper block on the lower at a cross position (with slight pressure of the finger downward at the central point, Fig. 3d), the air is squeezed out and the surfacesstick together . Then, we align the blocks by rotating the upper block (with lateral pressure of another finger keeping the vertical pressure on the centre). Another way is by direct sliding of the upper block along the lower one (with slight pressure of the finger downward, Fig. 3e).

If possible, blocks should be held on their side surfaces, otherwise the measuring surface that has been touched must be cleaned with petroleum ether, either to perform the measurement properly, or to continue with wringing of an additional block. When wringing, excessive force shall not be used, because the contact might be weaker (with greater thickness and variability), also some damage might occur on the edges or scratches on the measuring surfaces. Before storing a steel block, clean it with petroleum ether (or ethanol) and coat it with oil, to protect it from corrosion, especially if it has been touched it with bare hands. When reused, they shall be wiped with a dry cloth or petroleum ether.

As a new block is wrung repeatedly, the film thickness might shrink due to wear of the asperities of surface roughness. If a block becomes worn and scratched, its ability to wring decreases and the film thickness increases, so it is better to replace it with a new one, or to repair it, because even using it as a single may give erratic results. A block with a corroded measuring surface must be replaced immediately, because it will damage any other block it is wrung onto.

In some cases, we can repair a scratched surface with a special stone (Fig. 4). Again, we need to make sure that both surfaces, of the GB and of the stone, are clean and free from dust, before and after polishing. While a scratch remains visible, austerities are removed, and the GB has an improved ability to wring.

Gauge blocks are available in sets enabling them to be stacked to the desired length in a wide range. With GBs from the conventional set presented in Tab. 2, we can make any length up to three decimal places. For instance, 15.63 mm is a combination of four blocks (1.03 + 1.6 + 3 + 10) mm.

We try to assemble the desired length with as few blocks as possible to avoid accumulation of size errors. Single blocks with specific nominal lengths are available for this purpose. There are sets with which we can compose any measure in three decimal places. Depending on the desired minimum number of contacts in the assembly, individual blocks can be purchased, with which the same length can be assembled with one or two blocks less than in the conventional way of assembling. From Table 3, lengths up to 27.50 mm can be assembled only by two blocks, also in regions like (31.00 to 32.50) mm, for instance, 31.11 mm from 30 mm and 1.11 mm, while from Table 2 four blocks would be needed: (1.01 + 1.1 + 9 + 20) mm. In ranges like (27.51 to 29.99) mm we need three blocks from Table 3, for instance 27.51 mm is (1.51 + 1 + 25) mm, and 29.99 mm is (1.49 + 3.5 + 25) mm, a block less than from Table 2.

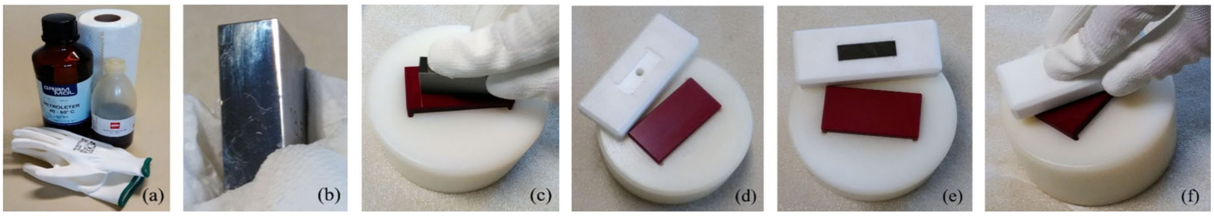


Fig. 4 Polishing with GB stone: (a) Petrol ether for cleaning and anti-corrosion oil, (b) Scratches, (c) Polishing with low pressure along the stone, (d-f) Accessory for a thin GBs

Table 2 Conventional set of gauge blocks (all in mm)

1.001	1.002	1.003	1.004	1.005	1.006	1.007	1.008	1.009
1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09
1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	19
1	2	3	4	5	6	7	8	9
10	20	30	40	50	60	70	80	90

Table 3 Individual gauge blocks (all in mm)

1.00	1.01	1.02	1.03	1.04	…	1.45	1.46	1.47	1.48	1.49
			1.5	1.6	1.7	1.8	1.9			
2.00	2.01	2.02	2.03	2.04	…	2.45	2.46	2.47	2.48	2.49
			2.5	2.6	2.7	2.8	2.9			
3	3.5	4	4.5	5	…	22.5	23	23.5	24	24.5
25	30	35	40	45	50	60	70	80	90	100

Standard grade blocks are made of a hardened steel alloy, while calibration grade blocks are often made of carbide or ceramic, because they are harder and wear less. The results of measurements should be given at the standard temperature 20 °C, which can be achieved by well-controlled air conditions in measuring rooms or chambers.

When the measuring systems and measurands are made of steel and steel blocks are used, the thermal expansion coefficients of the materials, α, are similar, and the length errors, ΔL, at temperature deviations, ΔT, might be negligible (Eq. 2). The thermal expansion coefficient of steel blocks is approximately $11.5 \cdot 10^{-6}\ \mathrm{K}^{-1}$, of ceramic $9.4 \cdot 10^{-6}\ \mathrm{K}^{-1}$ and of carbide $4.4 \cdot 10^{-6}\ \mathrm{K}^{-1}$. In the case of ceramic or carbide blocks, due to the significant difference of their coefficients compared to steel, it is necessary to pay more attention to the thermal stabilisation and to temperature correction of the measured length.

$$\Delta L = \alpha L \Delta T \tag{1}$$

$$\Delta L = \Delta\alpha L \Delta T \tag{2}$$

Among other influences, a change in a gauge block's temperature may be caused by touching it by hand. Gloves are recommended for handling them, tweezers could also be used to transfer individual gauge blocks, but, when assembling them, the blocks warm up noticeably, even if we manage to wring them in a very short time by using gloves. Therefore, we need to wait some time for the stack to be cooled. The cooling time depends on the required accuracy of measurement for which it is going to be applied.

2.2 Measurement of gauge block stack length

The purpose of the experiments was to determine the time of temperature stabilisation after assembling the blocks, and the repeatability of the residual contact. The deviation was observed with a precision GB comparator (Fig. 5), which is used in our laboratory for calibrating GB sets [1, 2]. The air temperature in the chamber was maintained at (20 ± 0.3) °C and monitored by a sensor calibrated with a measurement uncertainty of 0.05 K, installed near to the blocks. The GBs' temperature was measured with sensors with a 0.015 K measurement uncertainty (Fig. 6a). Immediately after wringing (Fig. 6b), the stack was inserted under the comparator's probe (Fig. 6c). During its temperature stabilisation, the deviation was measured periodically in comparison with the reference (Figs. 6c-e) until the temperature difference of the assembly and the reference became negligible. The length difference e_c was measured at the central points, and corrected for the length deviation of the reference e_{ref} (taken from the calibration certificate). The measurement uncertainty for the length of 50 mm, evaluated as our CMC in the accredited calibration procedure, is 0.055 µm for steel and 0.07 µm for ceramic GBs.

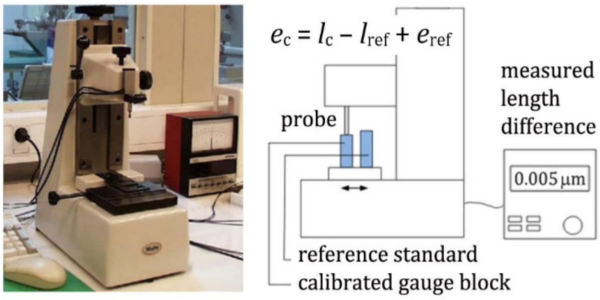


Fig. 5 Mechanical comparator for GB calibration

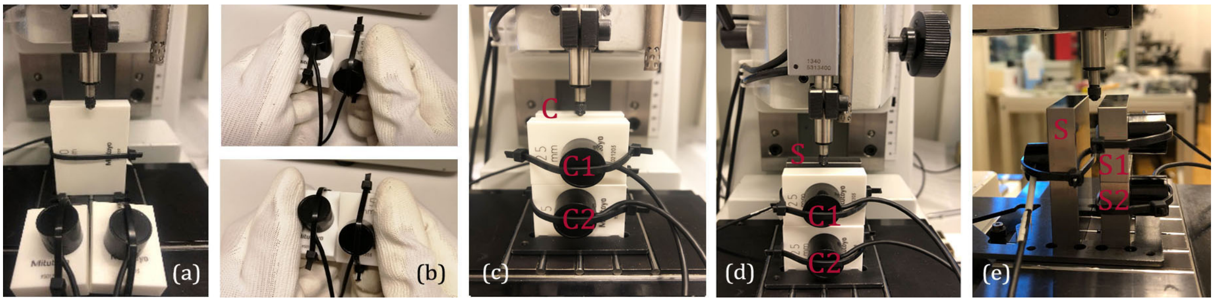


Fig. 6 Measurement of stack length by mechanical comparison: (a) Temperature stabilisation of GBs, (b) Wringing, (c) Comparison of the ceramic stack to the ceramic ref., (d) Ceramic stack to the steel, (e) Steel stack to the steel reference

3. Experimental results and discussion

The measurements were performed for three combinations (presented in Fig. 6). The stack of steel blocks S1 and S2, and the stack of ceramic blocks (C1 and C2) were compared with the (S) steel reference 50 mm from the master set (Grade K). The measurement with the ceramic stack was repeated also in comparison with the (C) ceramic reference 50 mm (Grade 0), in order to eliminate the difference in the thermal expansion coefficient. The blocks used for the wringing test were previously calibrated on the comparator. Their geometrical characteristics, derived from five points (as presented in Fig. 1) are given in Table 4 for five repeated measurements.

Table 4 Geometrical characteristics of the gauge blocks used in the experiments (all in μm)

(C1) ceramic 25 mm (Grade 0)			
e_c	v	f_o	f_u
-0.05	0.10	0.10	0.00
-0.05	0.09	0.09	0.00
-0.05	0.07	0.07	0.00
-0.05	0.09	0.08	0.01
-0.05	008	0.08	0.00

(S1) steel 25 mm (Grade K)			
e_c	v	f_o	f_u
0.01	0.02	0.00	0.02
0.02	0.02	0.00	0.02
0.02	0.03	0.00	0.03
0.01	0.02	0.00	0.02
0.01	0.02	0.00	0.02

(C2) ceramic 25 mm (Grade 0)			
e_c	v	f_o	f_u
-0.04	0.06	0.06	0.00
-0.05	0.07	0.07	0.00
-0.04	0.08	0.08	0.00
-0.03	0.06	0.06	0.00
-0.04	0.08	0.08	0.00

(S2) steel 25 mm (Grade 0)			
e_c	v	f_o	f_u
0.00	0.04	0.00	0.04
0.00	0.04	0.01	0.03
-0.01	0.05	0.01	0.04
0.00	0.05	0.01	0.04
0.00	0.05	0.01	0.04

By precise observation of these characteristics, taking into account that the lower contact layer is already included into the given central deviation e_c for both blocks in the stack, the additional geometrical contribution to the central deviation of the stack can be estimated from the characteristics given for the upper surface of the lower block, and the means of C2 in the ceramic stack and S2 in the steel stack (Fig. 6), respectively. From Table 4, the block S1 has f_o = 0.00 μm and the centre, as the highest level, has the deviation e_c = 0.014 μm (higher than the nominal value 25 mm); the block S2 has e_c = 0.00 μm and f_o = 0.01 μm. So, we can estimate the mutual geometrical contribution to be 0.024 μm. The C1 block has f_o = 0.084 μm (some asperity around the centre, which does not affect the length of the stack, because this block is on the top) and central deviation e_c = -0.05 μm (lower than the nominal value 25 mm). Similarly, C2 has e_c = -0.04 μm and f_o = 0.07 μm (some asperity around the centre, which could affect the length of the stack). So, we can estimate the mutual geometrical contribution to be -0.02 μm. Both estimated values are smaller than the measurement accuracy.

To determine the influencing factors, the repeatability of stack length was observed at different conditions, such as temperature of the hand, GB material and the addition of lubricant. Firstly, the single blocks were held in the hand (in a similar way as when assembling them) for 5 min and then cooled in air in the chamber, to estimate the heat transmission coefficient and time for stabilisation back to a standard temperature. The graphs in Fig. 7 show the heating of 25 mm long blocks, ceramic or steel, with a bare hand or with gloves, respectively (Fig. 7). It should be emphasised here that the general recommendation is to hold the blocks on their side faces. Surfaces touched by bare fingers should be cleaned with alcohol or petroleum ether, and coated with oil before being stored, as contact with the skin promotes corrosion.

Fig. 7 Heating blocks by holding: (a) With gloves, (b) With bare hands, (c) Stabilisation for 45 min

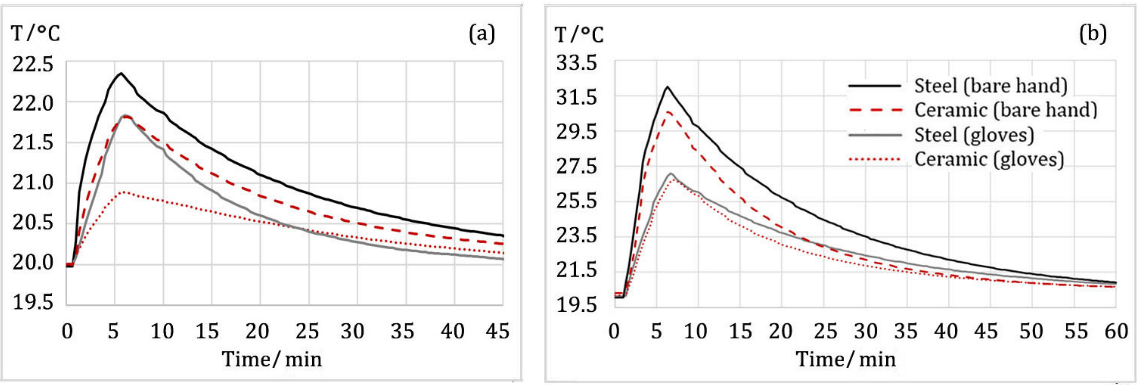


Fig. 8 Heating of 25 mm long blocks: (a) J.T. experimenter with plasticised gloves, (b) M.M. with cotton gloves

Fig. 8 presents the graphs of heating performed by two persons (a J.T. experimenter and an M.M. experimenter). In Fig. 8a the blocks were held with relatively cold hands and plasticised cotton gloves were used, while, in Fig. 8b, held with relatively warm hands and cotton gloves which were not plasticised. We can see that warming up depends strongly on the temperature of the hand (Table 5) and time of holding (Table 6). In the case of the higher temperature of the hand, warming was significantly faster. The heat transfer rates are higher at the beginning, due to the larger temperature differences in the hand-block contact.

Also, the cooling rate was initially higher, depending on the temperature difference between the block and the air. Within one hour, the temperature of the blocks returned to room temperature, regardless of the height of the temperature peak and the material, because the cooling rate depends more on the air convection than on the conductivity of the material.

Table 5 Variation in the hand's temperature during the experimentation (all in °C)

	J.T. experimenter			M.M. experimenter		
Bare hand	20.8	21.5	22.5	29.8	32.5	32.7
With gloves	20.5	21.1	21.8	27.4	30.5	31.0

Table 6 The slope of heating at the first 30 sec (K/10 sec)

	J.T. experimenter		M.M. experimenter	
	First 30 sec	During 5 min	First 30 sec	During 5 min
Steel (bare hand)	0.23	0.08	0.55	0.40
Ceramic (bare hand)	0.13	0.06	0.50	0.34
Steel (gloves)	0.07	0.06	0.37	0.23
Ceramic (gloves)	0.04	0.03	0.25	0.22

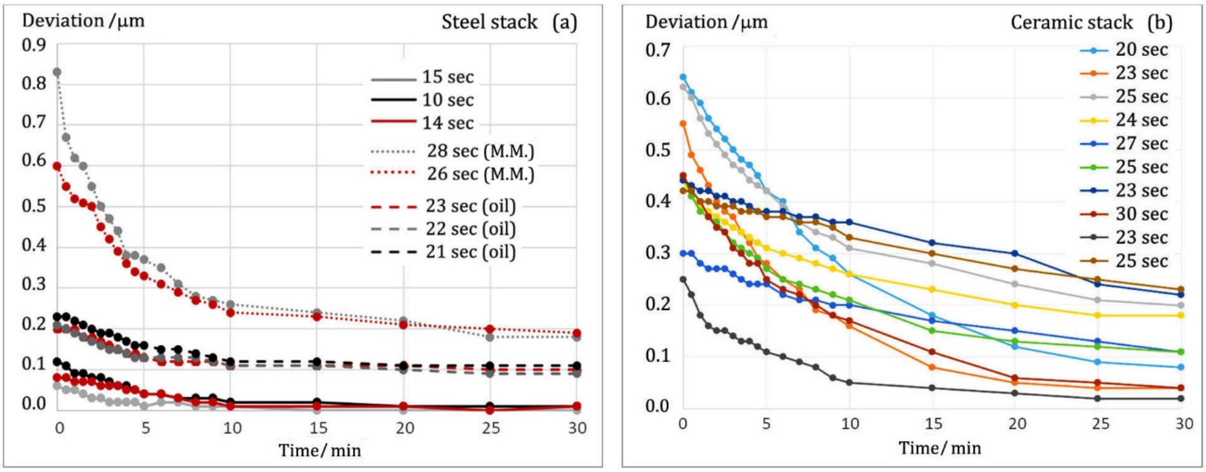
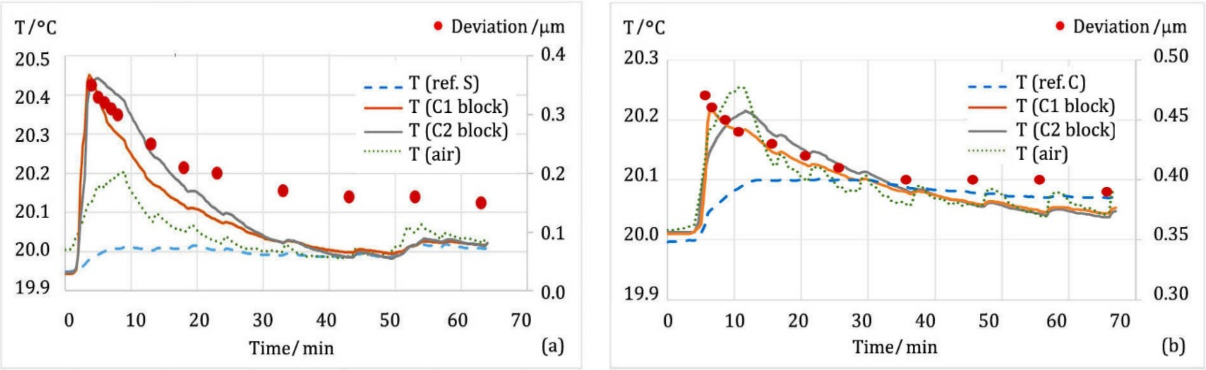


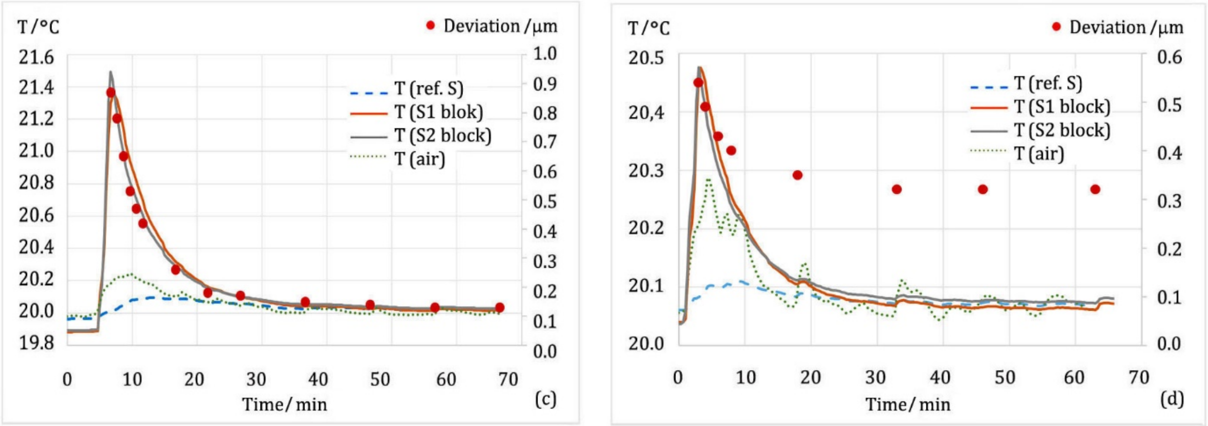
Fig. 9 Deviation of stack length after wringing: (a) Steel stack (J2 + J1) by J.T. with plasticised gloves (at conventional or extra oil application) and M.M. with cotton gloves, (b) Ceramic stack (K2 + K1) by J.T. with plasticised gloves

Some measurements of the stack length were performed on the comparator within 30 seconds of cooling, starting immediately after wringing. The length deviations of the stack in comparison to the reference block are presented in Fig. 9. The time needed for wringing is given in the legend for each repetition. The major cause of the wide range of deviations was the difference in temperature of the hands, time of wringing, while the residual deviations depend on oil application, wear of the gauge blocks and wringing skills. The ceramic blocks were more difficult to wring and easier to separate in comparison to the steel blocks, where traces of oil contributed to stronger adhesion. The major reason for the increased length was warming by hands.



(a) Ceramic stack wrung by J.T. (30 sec)

(b) Ceramic stack wrung by J.T. (18 sec)



(c) Steel stack wrung by M.M. (28 sec)

(d) Steel stack by J.T. (18 sec) with anticorrosive grease

Fig. 10 Temperatures and length deviation of the stacks

Table 7 The residual length deviations (all in μm)

Residual length deviation	After one hour	After 16 hours
Ceramic stack (Fig. 10a)	0.15	0.15
Ceramic stack (Fig. 10b)	0.39	0.40
Steel stack (Fig. 10c)	0.13	0.12
Steel stack with grease (Fig. 10d)	0.32	0.31

The precise observations on the comparator were repeated with the temperature of all blocks and the air monitored in well controlled conditions in the laboratory chamber (Fig. 6). Different cases are collected on Fig. 10. We can see that the temperature of the stack stabilised within one hour. Some fluctuation of the air temperature appeared, due to the experimenter's presence, at the beginning (during wringing and installation of the stack onto the comparator), and periodically during performance of the measurement on the comparator, but this didn't affect the residual deviation of the stack significantly (because both the stack and the reference block had the same temperature of the air at the end), as well it decreased very little the initial length deviation of the stack, maximally 5 % (because the reference block responded slowly, with the quotient between the temperature of refence and the air approximately 0.2).

The residual deviations were checked the next day and remained almost the same (Table 7). The measured deviation is the sum of the residual deviation and the deviation due to the temperature difference between the assembly and the reference block, which can be calculated by Eq. 1.

Taking from Fig. 10 the time of wringing and the initial temperature change, the slope of heating is around 0.55 K/10 sec by the M.M. experimenter, 0.15 K/10 sec for the ceramic and 0.25 K/10 sec for the steel by the J.T. experimenter, which is higher than when the blocks were just held (Table 6), i.e. without active work of the hands. It is known that friction between surfaces can heat the material significantly [13, 14], depending on load, friction coefficient and lubrication [15]. In cases of blocks' wringing, these contributions are rather negligible.

Fig. 11 presents repetitions of the sliding of blocks similarly to the previous wringing (Fig. 10), but in this observation the blocks were held with thick insulation material to prevent the heat transfer from the hands, and the sensors were attached to the side surfaces of the blocks just at the edge, to monitor the temperature close to the sliding surfaces. From the temperature rise for both blocks, corrected for other possible influences from Fig. 11d, the contribution of friction was around 0.03 K/10 sec.

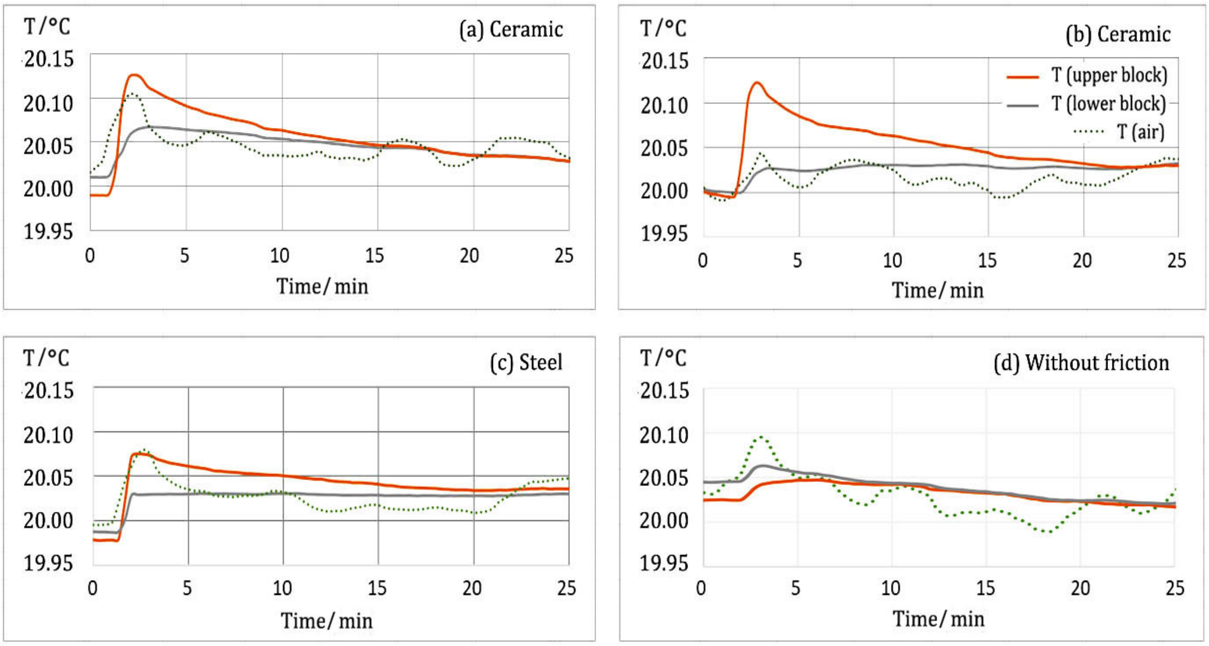


Fig. 11 Temperature rise at the estimated force (perpendicular to the surface) 10 N during 35 sec of sliding

4. Conclusion

Gauge blocks used as a reference, either as single blocks wrung onto a plate or assembled together, have some deviation in length due to inter-surface contact thickness, which depends on many factors: the quality of the blocks (grade, geometric characteristics, roughness, and wear), surface preparation (cleaning and use of a lubricant), the method of assembly, time and wringing skills, hand temperature and insulating protection of gloves.

To determine the quality of blocks, it is recommended to calibrate gauge blocks periodically. In the calibration certificate, the given length of a block already includes the thickness of the contact of the lower measuring surface (when wrung onto an ideal base), and the geometric contribution to the upper contact can be estimated from the given variance of the upper measuring surface. Depending on the length of the gauge blocks and their grade, a tolerance of 0.1 μm variance is allowed up to 25 mm, 0.16 μm for grade 1 and 0.3 μm for grade 2. In our experiment, gauge blocks (grade 0) with such geometric characteristics were selected that the final geometric contribution was negligible compared to the reliability of the measurement procedure on the comparator.

The main contribution in this article are precise insitu measurements with length comparator and temperature sensors in well air controlled laboratory environment to determine the length uncertainty of stacks due to wringing process. The results that initial deviations due to heating by hands are not negligible in comparison to the geometrical deviations (that are determined by quality of blocks used for assembly). They vary with time, way of wringing and temperature of hands. The results in the article are given for the range of cold and extremely warm hands. The use of plasticised gloves is highly recommended to reduce the temperature contribution, as the heating rate was slowed by about half in both cases.

The observations regarding the preparation of bloks' surface showed that in the case of oil traces (after oil application the surface is wiped with petrolether) the adhesion increased, the contact is smaller and with better repeatability. Additional application of oil (wiped just with a dry cloth or paper towel) is useful for lower quality surfaces, this makes the blocks easier to wring, but the contribution of the contact is greater. In our experiments, the oil layer contributed 0.1 μm and the grease 0.2 μm.

After wringing, the stacks shall be allowed to cool to operating temperature before using them, depending on the required reliability of the measurements, where they are use as a reference. Our experiments have shown that one hour is enough at well controlled air conditions. The residual deviations after one hour were the same as after one day of stabilization. The residual value can be estimated from the geometrical quality of used blocks (depending on wear and grade determined from calibration certificate) and slightly varying with application of a lubricant, as was proved in the case of grade 0.

Acknowledgement

The authors acknowledge the financial support from the Slovenian Research Agency (Research Core Funding No. P2-0190), as well as from the Metrology Institute of the Republic of Slovenia (funding of the National Standard of length; Contract No. C3212-10-000072).

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