Kupfer*Digital* mechanical testing datasets: Stress relaxation and low-cycle fatigue (LCF) tests

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Abstract:
The Kupfer*Digital* project deals with the development of a data ecosystem for digital materials research on the basis of ontology-based digital representations of copper and copper alloys. This document provides exemplary mechanical testing datasets for training the developed Kupfer*Digital* infrastructures. Different types of cast copper alloys were provided for this research and their mechanical testing (stress relaxation and low-cycle fatigue) was performed in the accredited materials testing laboratory, while the test results were reported according to the DIN/ISO standards and attached with the maximum possible metadata about the sample history, equipment, and calibration. The attached content file consisted of the obtained primary raw testing data as well as the secondary datasets of these tests containing the detailed metadata of mechanical testing methods. Such test data files are processed by the Kupfer*Digital* digital tools to be converted to standardized machine-readable data files.
Keywords: Copper alloys, dataset, mechanical testing, stress relaxation, low-cycle fatigue.

1. Introduction

Plenty of mechanical testing data are generated daily in thousands of materials test labs around the world, while most of these data do not meet the criteria of being Findable, Accessible, Interoperable, and Reusable (FAIR), and therefore cannot be (re-)used for data-driven product development purposes [1]. The processes digitalization and formulating the formal standardized knowledge representation through the ontologies are the powerful approaches for implementing the FAIR principles and building the comprehensive database infrastructure [1]. In this regard, the German digitalization initiative innovation platform MaterialDigital (PMD) was established in 2019 to accelerate the efforts toward digitalization in the material science and technology community [2]. The "Kupfer*Digital*" (copper digital) project is one of the funded projects within the MaterialDigital initiative that aims to develop a data ecosystem for digital materials research based on ontology-based digital representations of copper and copper alloys [3]. In the sub-project Kupfer*Digital*, BAM is working on the digitalization of materials mechanical testing data. Here, different types of mechanical testing data are required for training the digitalization process of the mechanical testing methods. We already published a dataset which contains the project mechanical testing dataset for Brinell hardness, Vickers hardness and tensile testing [4]. The current dataset also aims to gather further Kupfer*Digital* mechanical testing datasets for the stress relaxation and low-cycle fatigue (LCF) tests.

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2. Materials and method

2.1. Materials

Nine different cast copper alloys were provided by Deutsches Kupferinstitut (DKI) and fem Forschungsinstitut (fem), and their composition and processing history are represented in Table 1.

Table 1. Nominal composition, provider, and processing history of investigated copper alloys.

ID	Alloy composition (wt.%)	Provider	Processing method
A	CuZn38As	DKI	Casting, hot and cold extrusion
B	CuZn21Si3P	DKI	Casting and hot extrusion
C	CuNiSi	fem	Continuous casting
D	CuSn6	fem	Continuous casting
E	CuSn12	fem	Continuous casting
F	CuNi12Al3	fem	Continuous casting
G	CuNi6Sn4	fem	Continuous casting + heat treatment*
H	CuSn8Ni2	fem	Continuous casting
I	CuZn23Si2.5	fem	Continuous casting

* The heat treatment consisted of a heating step at 800 °C for 40 min followed by the water quenching, and another heating step at 410 °C for 3 hours.

2.2. Mechanical testing

The mechanical testing was performed in the accredited materials testing laboratory of the Bundesanstalt für Materialforschung und -prüfung (BAM). The test results were reported according to the DIN/ISO standards and attached with the maximum possible metadata about the sample history, equipment, calibration, etc.

The stress relaxation tests were performed according to the DIN EN 10319-1:2003 standard [5]. The dimensions of the test specimens are shown in Fig. 1a. The test pieces have a cylindrical cross-section and a total length of 54 mm (parallel length of 30 mm). The tests were done in air on a 100 kN electromechanical testing machine (MTS Systems, Model C45.105; class 1 calibration) with a strain rate of 0.025 %/s. An axial extensometer (MTS Systems; type 632.51C-05; class 0.5 calibration) of 21 mm nominal gauge length was used. Stress relaxation started after reaching 1 % total strain and continued for 24 hours while the temperature was kept constant at 100 °C. Small variations in the cooling water temperature (up to ±1,5°C) lead to a drift in the extensometer signal. As the test is performed under strain control, this drift leads to noise in the force signal.

The LCF tests were performed according to the ISO 12106:2017 standard [6]. The dimensions of the test specimens are shown in Fig. 1b. The test pieces have a cylindrical cross-section and a total length of 95 mm (parallel length of 17 mm). LCF tests were done on a 100 kN electromechanical testing machine (Instron; type 8561; class 1 calibration) in air at room temperature. An axial extensometer (MTS Systems; type 632.51C-04; 12 mm nominal gauge length; class 1 calibration) was used. The tests were performed at different strain amplitudes at a strain ratio ($R_e = e_{min}/e_{max}$) of -1 and a strain rate of 10^{-3}/s, respectively. After fatigue testing, the number of cycles to failure, N_f, was determined for each test by applying a failure criterion of 10 % load drop of the maximum peak stress in the cyclic stress response curve vs. the number of cycles.

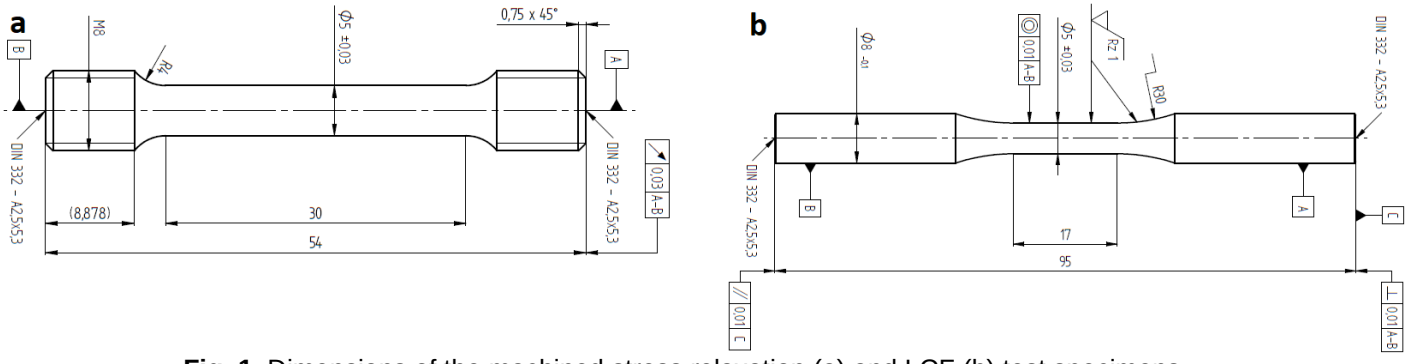

Fig. 1. Dimensions of the machined stress relaxation (a) and LCF (b) test specimens.

2.3. Description of files

The different copper alloys were tested by the methods mentioned in 2.2, and the primary raw test data as well as the secondary datasets were generated and stored in the repository. The primary data were recorded in the CSV files using the testing machines' software. For stress relaxation test the dataset was edited: the stress-strain-curves were shifted such that the fit to the elastic range of the curve passes to zero point. In addition, the measured data after 24 h relaxation were deleted. The secondary datasets are the tabular datasheets that were created by the materials scientists for gathering the main measurement metadata of all samples in an XLSX file. Table 2 lists and describes all the related test data given in this repository.

Table 2. Describing the mechanical testing data files of the current repository.

Type		File	Description
Stress relaxation test	Primary data	Stress relaxation_A_04.lis	CSV data for stress relaxation testing of sample A_04
		Stress relaxation_B_03.lis	CSV data for stress relaxation testing of sample B_03
		Stress relaxation_B_04.lis	CSV data for stress relaxation testing of sample B_04
		Stress relaxation_C_10.lis	CSV data for stress relaxation testing of sample C_10
		Stress relaxation_C_11.lis	CSV data for stress relaxation testing of sample C_11
		Stress relaxation_D_03.lis	CSV data for stress relaxation testing of sample D_03
		Stress relaxation_E_03.lis	CSV data for stress relaxation testing of sample E_03
		Stress relaxation_F_03.lis	CSV data for stress relaxation testing of sample F_03
		Stress relaxation_G_07.lis	CSV data for stress relaxation testing of sample G_07
		Stress relaxation_G_09.lis	CSV data for stress relaxation testing of sample G_09
		Stress relaxation_G_15.lis	CSV data for stress relaxation testing of sample G_15
		Stress relaxation_H_07.lis	CSV data for stress relaxation testing of sample H_07
		Stress relaxation_H_09.lis	CSV data for stress relaxation testing of sample H_09
		Stress relaxation_H_15.lis	CSV data for stress relaxation testing of sample H_15
		Stress relaxation_I_07.lis	CSV data for stress relaxation testing of sample I_07
		Stress relaxation_I_14.lis	CSV data for stress relaxation testing of sample I_14
		Stress relaxation_I_15.lis	CSV data for stress relaxation testing of sample I_15
	Secondary data	Stress relaxation secondary dataset.xlsx	Excel dataset of the stress relaxation metadata of all tests
LCF test	Primary data	LCF_C_05.lis	CSV type data for LCF testing of sample C_05
		LCF_G_21.lis	CSV type data for LCF testing of sample G_21
		LCF_G_22.lis	CSV type data for LCF testing of sample G_22
		LCF_G_23.lis	CSV type data for LCF testing of sample G_23
		LCF_G_24.lis	CSV type data for LCF testing of sample G_24
		LCF_G_25.lis	CSV type data for LCF testing of sample G_25
		LCF_G_26.lis	CSV type data for LCF testing of sample G_26
		LCF_G_27.lis	CSV type data for LCF testing of sample G_27
		LCF_H_21.lis	CSV type data for LCF testing of sample H_21
		LCF_H_22.lis	CSV type data for LCF testing of sample H_22
		LCF_H_23.lis	CSV type data for LCF testing of sample H_23
		LCF_H_24.lis	CSV type data for LCF testing of sample H_24
		LCF_H_25.lis	CSV type data for LCF testing of sample H_25
		LCF_H_26.lis	CSV type data for LCF testing of sample H_26
		LCF_H_27.lis	CSV type data for LCF testing of sample H_27
		LCF_I_21.lis	CSV type data for LCF testing of sample I_21
		LCF_I_22.lis	CSV type data for LCF testing of sample I_22
		LCF_I_24.lis	CSV type data for LCF testing of sample I_24
		LCF_I_25.lis	CSV type data for LCF testing of sample I_25
	Secondary data	LCF secondary dataset.xlsx	Excel dataset of the LCF metadata of all tests

3. Results

Characteristic material parameters and measurement metadata were extracted from the test files of section 2.3, which are listed as secondary datasets of the testing method. Tables 3 and 4 represent parts of such data on the main measured mechanical properties of the different copper alloys.

Note: The values given for slope of elastic region, m_E, and yield strength, $R_{p0.2}$, are for information only, as they were not determined from tensile tests (and their evaluation is not intended according to DIN EN 10319-1:2003). Deviating from DIN EN 10319-1:2003, in some

cases the residual stress given in Table 3 is not the remaining stress after 24 h, but the minimum stress during the test. However, the differences are very small.

Table 3. Exemplary secondary data from the Kupfer*Digital* stress relaxation testing dataset.

Sample	Original Cross Section Area mm²	Yield Strength $R_{p0.2}$ MPa	Slope of elastic region m_E GPa	Initial Strain %	Initial Stress MPa	Residual Stress after 24 h at 100 °C MPa	Relaxed Stress after 24 h at 100 °C %
A_04	19.630	245	47.5	1.00	250	216	13.6
B_03	19.656	367	88.5	1.00	474	419	11.6
B_04	19.677	377	86.1	1.00	475	424	10.7
C_10	19.627	77.6	53.7	1.00	95.1	87.9	7.6
C_11	19.640	78.3	50.8	0.99	98.6	91.4	7.3
D_03	19.687	103	64.8	1.01	113	100	11.5
E_03	19.664	155	105	0.99	184	171	7.1
F_03	19.653	415	102	0.99	441	435	1.4
G_07	19.748	243	61.5	0.99	292	277	5.1
G_09	19.687	265	56.2	1.01	308	291	5.5
G_15	19.695	206	59.6	1.01	249	235	5.6
H_07	19.742	150	51.3	1.02	164	152	7.3
H_09	19.700	148	53.4	1.01	161	149	7.5
H_15	19.700	143	47.5	1.01	154	144	6.5
I_07	19.698	131	68.1	1.01	167	161	3.6
I_14	19.703	124	63.3	1.00	158	149	5.7
I_15	19.784	127	62.7	1.01	157	145	7.6

Table 4. Exemplary secondary data from the Kupfer*Digital* LCF testing dataset; more than 100000 cycles were defined as run out.

Sample	Cross-section area (mm^2)	e_{max} (%)	e_{min} (%)	Fatigue life, $N_{f10\%}$ (-)
C_05	18.449	0.40	-0.40	47758
G_21	19.353	0.30	-0.30	27813
G_22	19.400	0.45	-0.45	8183
G_23	19.405	0.40	-0.40	7868
G_24	19.417	0.35	-0.35	12422
G_25	19.401	0.50	-0.50	3291
G_26	19.438	0.45	-0.45	5617
G_27	19.371	0.40	-0.40	8788
H_21	19.284	0.55	-0.55	21040
H_22	19.150	0.45	-0.45	35640
H_23	19.265	0.60	-0.60	13463
H_24	19.292	0.35	-0.35	run out
H_25	19.373	0.50	-0.50	29038
H_26	19.368	0.45	-0.45	65372
H_27	19.172	0.40	-0.40	run out
I_21	19.182	0.50	-0.50	9726
I_22	18.791	0.45	-0.45	15576
I_24	19.217	0.35	-0.35	50749
I_25	18.907	0.40	-0.40	20789

4. Conclusion and perspective

To train the digitalization of mechanical testing processes within the KupferDigital project, different copper alloys were provided, and their mechanical properties were determined by stress relaxation and LCF testing methods. The primary raw testing data as well as the secondary datasets containing all required test metadata are provided. The datasets are supposed to provide exemplary data as a basis for experimental data inclusion, conversion, and structuring (data management and processing) that leads to semantical expressivity as well as for materials science and engineering experts being generally interested in material properties and knowledge. Eventually, the analysis of mechanical testing data and converting them to the FAIR data will be discussed in Kupfer*Digital* publications.

Acknowledgments
The authors acknowledge the financial support of the Federal Ministry of Education and Research (BMBF) through the project ‘KupferDigital - Datenökosystem für die digitale Materialentwicklung auf Basis Ontologie-basierter digitaler Repräsentationen von Kupfer und Kupferlegierungen’ [grant numbers 13XP5119C and 13XP5119A]. We also appreciate Dr. Ladji Tikana and Deutsches Kupferinstitut (Düsseldorf, Germany) for providing some of the copper alloys of this project.

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