ESIS TC5 European Round Robin on Dynamic Compression Testing

Jan Džugan[1, a], Hugh MacGillivray[2,b], Uwe Mayer[3,c], Václav Mentl[4,d] and Celia Watson[5,e]

[1]COMTES FHT, Průmyslová 995, 334 41 Dobřany, Czech Republic

[2]Imperial College London, Department of Mechanical Engineering, South Kensington Campus, London SW7 2AZ, United Kingdom

[3]MPA Stuttgart, Pfaffenwaldring 32, 70569 Stuttgart (Vaihingen), Deutschland

[4]SKODA Research Ltd., Tylova 1/57, 316 00 Plzeň, Czech Republic

[5]Cranfield University, Shrivenham, Swindon. SN6 8LA, United Kingdom

[a]jan.dzugan@comtesfht.cz, [b]h.macgill@imperial.ac.uk, [c]Uwe.Mayer@mpa.uni-stuttgart.de, [d]vaclav.mentl@skodavyzkum.cz, [e]c.h.watson@cranfield.ac.uk

Keywords: Dynamic test, compression test, round robin.

Abstract. The paper deals with results of dynamic compression round-robin tests organized within the framework of ESIS TC5. The goal of the presented round-robin was to prove the comparability of tests performed in different European laboratories. Different testing machines were also applied to prove the applicability of current testing methodology to various testing equipment. Drop weight towers, a servohydraulic machine and a converted Charpy impact pendulum were used in the current study.

Introduction

ESIS TC5 subcommittee on testing at intermediate strain rates deals with development of testing procedures and standards. The main field of interest have been the development of standards for pre-cracked Charpy testing, Mini-Charpy testing, dynamic tensile test of sheet metals and the newly-developed procedure for dynamic compression tests. Within the frame of the standard procedure for dynamic compression tests development, two round robins were performed. Laboratories from several European countries took part in these tests. Each laboratory performed tests according to an agreed procedure, with recommended total strain and strain rate. Three different types of testing machines were employed in theses tests: Drop Weight Tower (DWT), High Speed Servohydraulic Machine (HSSM) and Converted Charpy Impact Pendulum (CCIP).

Experimental material, samples and test conditions

There were two rounds of round-robin tests. In the first one, an aluminium alloy was investigated and on the basis of these results a second round was performed on Armco iron. Two conditions of Al-alloy 1050 were investigated. The material was delivered in the form of sheets 9,5mm thick. The material had undergone 76% cold work, being rolled from 40mm to 9.5mm with no inter-annealing. The first investigated state of the Al-alloy was in the as-rolled condition. The second state additionally underwent the following procedure: heating to 600°C for 10 minutes followed by a furnace cooling to 350°C, providing a fully re-crystallized microstructure. Cylindrical samples of diameter 9mm and height 9mm were machined from Al-alloy sheets for both material states. In the case of Armco iron, cylindrical samples of diameter 5mm and height 5mm were machined.

During the test the use of lubricant to reduce friction on the specimen end faces was required. There were basically used two kind of lubricant in the case of Al-alloy testing – MoS2 grease and PTFE shims. In the case of Armco iron testing, MoS2 grease was used by all participants. Due to

the use of different testing machines, testing conditions had to be specified so that tests could be performed by each of the testing system. Finally, it was decided that sample deformation after test has to be between 40 and 60% of the original height and testing velocities were kept between 1 and 2,5 m/s. Testing velocity in the case of servohydraulic machine can be clearly defined regardless of expected forces and deformations. In the case of DWT and CCIP, sample total deformation is defined the impact energy of falling mass. The impact energy results from the impact mass weight and impact velocity. While the impact velocity can be usually continuously adjusted for considered machines, weight of impact mass can be changed in only predefined steps. Each of the materials investigated exhibits different deformation behaviour, thus in order to attain required deformation different test parameters had to be used in order to attain the desired goal.

Dynamic compression tests

Dynamic compression tests were carried out in the following laboratories: COMTES FHT (CTS), Dobřany, Czech Republic – CCIP, Cranfield University (DCMT), Shrivenham, United Kingdom – DWT, Imperial College (IC), London, United Kingdom - DWT, Materialprüfungsanstalt Universität (MPA), Stuttgart, Germany – HSSM and SKODA Research Institute (SKODA), Pilsen, Czech Republic - CCIP. Each laboratory was sent a batch of machined samples containing 5 specimens from all materials of interest. Information on samples dimensions, test velocities and strain rates can be found in **Tables. 1** and **2**. Tests were carried out at room temperatures.

Force measurement was ~~done~~ by a strain gauge-based load cell for CTS, MPA and SKODA. IC and DCMD used piezocrystal-based loadcells. Sample deformation was measured by a 500kHz inductive gauge at IC, Digital optical read head at DCMT, and LVDT at MPA. CTS and SKODA calculated deformation by double integration of force versus time record.

Examples of records of dynamic compression tests can be found in **Figures. 1-5**. Force versus time records are shown here for all falling mass machines, where these data were originally measured without any processing.

Tab. 1. Testing conditions – ARMCO iron

Participant	Specimen	D_0 mm	D_f mm	H_0 mm	H_f mm	v_0 m/s	v_f m/s	Average strain rate s^{-1}	Lubricant
MPA	ARM5	5,00	--	5,00	--	1,60	0,8	320	MoS2
	ARM7	5,00	--	5,03	--	1,60	0,9	318	MoS2
	ARM8	5,03	--	5,05	--	1,60	1,0	317	MoS2
	ARM9	5,01	--	5,03	--	1,60	1,0	318	MoS2
DCMT	AM4	5,00	7,14	5,01	2,51	2,03	0,0	405	MoS2
	AM3	5,00	7,10	4,99	2,49	2,03	0,0	407	MoS2
	AM2	5,00	7,11	4,95	2,50	2,00	0,0	404	MoS2
	AM1	5,00	7,17	4,94	2,46	2,03	0,0	411	MoS2
IC	ARM 1	5,02	7,57	4,75	2,13	1,82	0	383	MoS2
	ARM 2	4,95	7,37	4,97	2,35	1,82	0	366	MoS2
	ARM 3	5,01	7,34	5,05	2,41	1,82	0	360	MoS2
	ARM 4	5,03	7,43	4,93	2,36	1,82	0	369	MoS2
	ARM 6	4,94	7,36	5,02	2,35	1,82	0	363	MoS2
COMTES	AM11	5,00	8,02	5,161	1,98	2,54	0	493	MoS2
	AM13	5,01	7,84	5,015	2,08	2,34	0	467	MoS2
	AM14	5,03	7,81	5,103	2,15	2,34	0	459	MoS2
	AM15	5,03	7,72	5,094	2,17	2,34	0	460	MoS2

Tab. 2. Testing conditions – Al alloys

Laboratory	Specimen	D_0 mm	D_f mm	H_0 mm	H_f mm	v_0 m/s	v_f m/s	Strain rate s^{-1}	Lubricant
DCMT	Al_1_3	8,96	11,80	9,01	5,47	1,96	0	277	PTFE
	Al_1_4	8,97	11,69	9,01	5,45	1,96	0	275	PTFE
	Al_1_5	8,96	11,65	9,03	5,48	1,96	0	276	PTFE
	Al_2_1	9,01	12,70	8,99	4,60	1,96	0	218	PTFE
	Al_2_2	8,98	12,65	8,99	4,61	1,96	0	218	PTFE
	Al_2_3	8,97	12,73	8,99	4,60	1,96	0	219	PTFE
ŠKODA	Al_1_1	9,01	11,45	9,00	5,92	2,02	0	224	MoS2
	Al_1_2	9,02	11,94	9,00	5,43	2,25	0	249	MoS2
	Al_1_3	8,99	12,95	9,00	4,81	2,47	0	275	MoS2
	Al_1_4	9,01	13,62	9,00	4,00	2,91	0	323	MoS2
	Al_1_5	8,99	13,25	9,04	4,67	2,91	0	324	MoS2
	Al_2_3	9,00	13,54	9,00	3,84	2,47	0	275	MoS2
	Al_2_4	8,99	13,68	9,00	3,96	2,47	0	275	MoS2
	Al_2_5	9,01	13,72	9,00	3,99	2,47	0	274	MoS2
	Al_2_6	8,99	13,84	9,00	3,91	2,47	0	275	MoS2
	Al_2_7	9,00	13,56	9,00	4,08	2,47	0	275	MoS2
IC	Al_1_1	9,01	11,88	9,00	4,92	2,05	0	227	PTFE
	Al_1_2	9,04	11,97	9,03	4,98	2,05	0	227	PTFE
	Al_1_3	9,01	11,81	9,00	4,93	2,05	0	227	PTFE
	Al_1_4	9,00	11,89	9,02	4,95	2,05	0	228	PTFE
	Al_2_1	8,96	13,04	9,05	4,15	2,05	0	229	PTFE
	Al_2_2	9,00	13,01	9,04	4,13	2,05	0	228	PTFE
	Al_2_3	9,00	13,06	9,01	4,09	2,05	0	228	PTFE
	Al_2_4	8,98	13,01	9,01	4,11	2,05	0	228	PTFE
MPA	Al_1_1	9,00	12,80	9,00	4,50	1,20	1,2	133	MoS2
	Al_1_2	9,00	13,05	9,00	4,50	1,20	1,2	133	MoS2
	Al_1_3	9,02	13,25	9,00	4,50	1,20	1,2	133	MoS2
	Al_1_4	9,00	13,05	9,02	4,50	1,20	1,2	133	MoS2
	Al_1_6	9,00	13,00	9,00	4,50	1,20	1,2	133	MoS2
	Al_2_1	8,95	11,65	9,02	5,40	1,20	1,2	134	MoS2
	Al_2_2	8,97	11,80	9,07	5,40	1,20	1,2	134	MoS2
	Al_2_3	8,97	12,00	9,06	5,40	1,20	1,2	134	MoS2
	Al_2_5	8,99	12,20	9,02	5,10	1,20	1,2	133	MoS2
	Al_2_6	9,00	12,30	9,08	5,00	1,20	1,2	133	MoS2
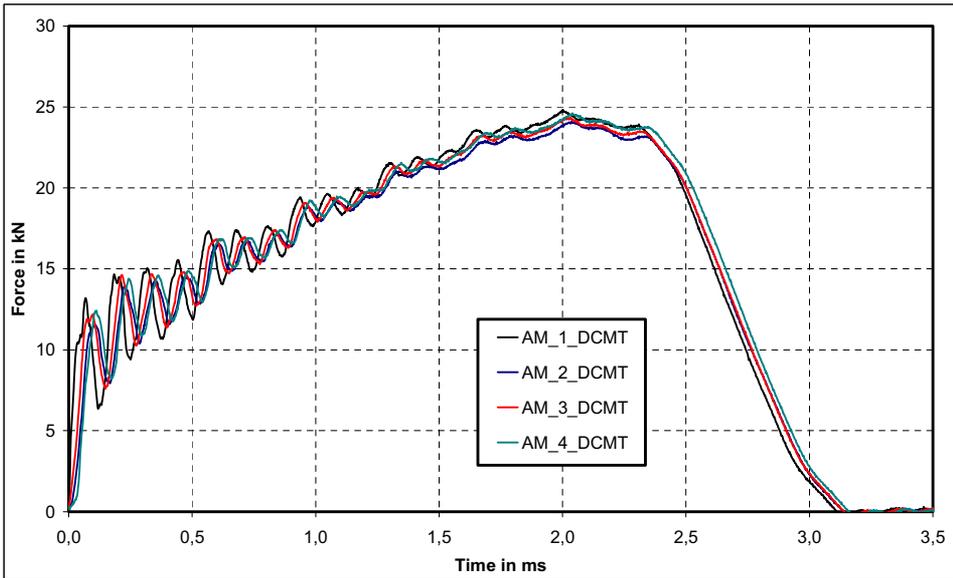
Fig. 1. Example of dynamic compression tests of ARMCO iron – Drop Weight Tower - DCMT
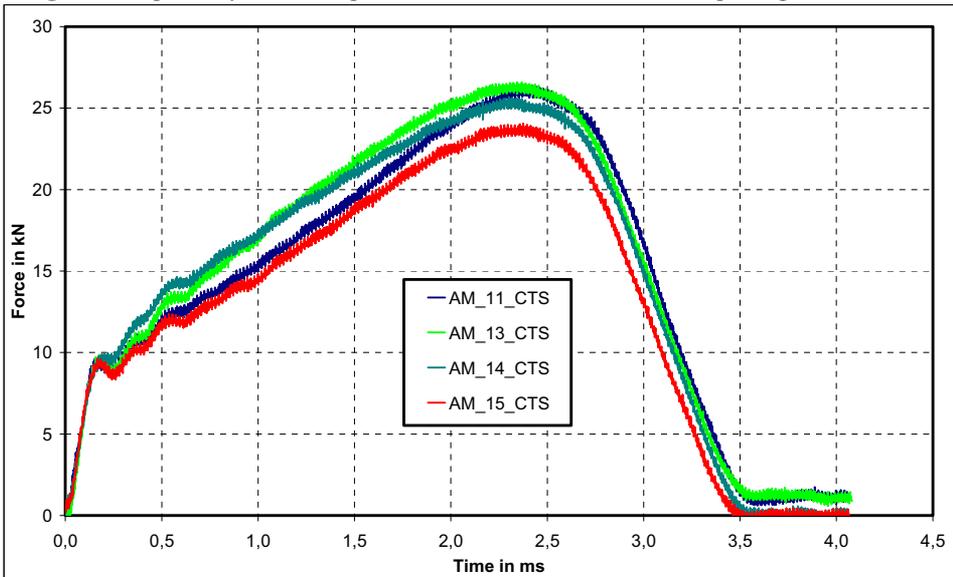
Fig. 2. Example of dynamic compression tests of ARMCO iron – Converted Charpy Pendulum - CTS
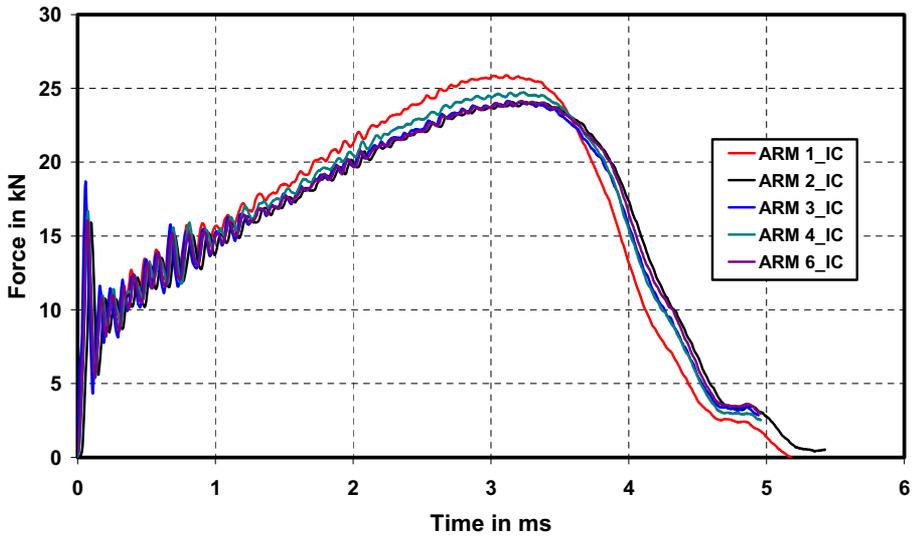
Fig. 3. Example of dynamic compression tests of ARMCO iron – Drop Weight Tower – IC
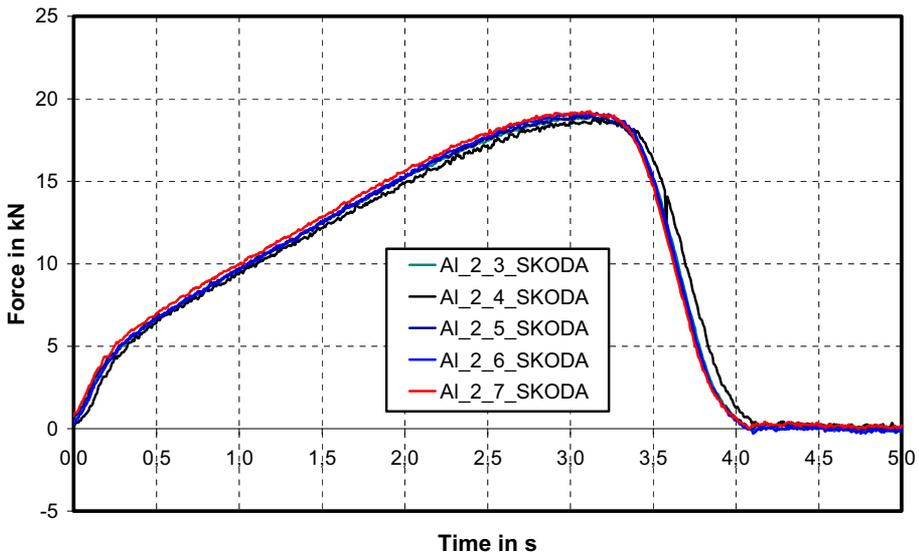
Fig. 4. Example of dynamic compression tests of Al_2 alloy – Converted Charpy Pendulum – SKODA
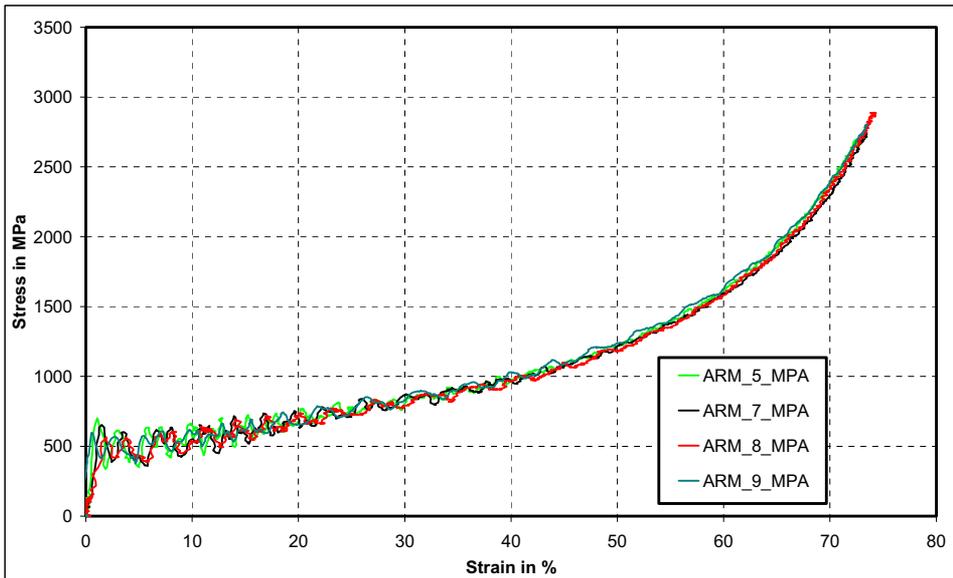
Fig. 5. Example of dynamic compression tests of ARMCO iron – Servohydraulic machine - MPA

Results Discussion

Results of dynamic compression tests performed on three batches of samples are summarized in **Figs. 6, 7, 8**. The first round of tests on Al-alloy provided very good results considering that three different kinds of testing machines were used and different procedures for deformation measurements were employed. Observing curves in stress-strain coordinates displayed in **Figs. 6** and **7,** there can be seen that the course of all curves is the same. Unfortunately, the data measured by IC were trimmed in the initial part of the curve, but their agreement with MPA data at later stages is clear for both states of Al-Alloy. The curves obtained by SKODA and DCMD are slightly lower. The curves exhibit very good agreement at higher strain values, while in the initial part of the curves (elastic region) larger differences are visible. This difference is the result of different systems dynamic response resulting in various "smoothing" of the curves at this early stage.

The results of the first test on Al-Alloy were very good considering the relative complexity of the test variables. For the second round a check of loadcell calibration was recommended to all participants. The results of the second round on Armco iron are displayed in the **Fig. 8**. Checking of the loadcell calibrations seems to produce excellent agreement. It can be clearly seen that there is one family of curves for all testing laboratories, collapsing almost into a single curve, in the second round. Perfect agreement was obtained at strains above 5 %. At lower strain values difference in system's dynamic response plays a significant role and thus larger discrepancies are noticed here. The worst dynamic response seems to be for the CTS curve where the instrumentation seems to be not sensitive enough for small strain measurement. However, compression tests are generally used for large deformations measurement and thus the results obtained by all participants are very good proving suitability of currently used testing methodology to all considered kinds of testing machines.
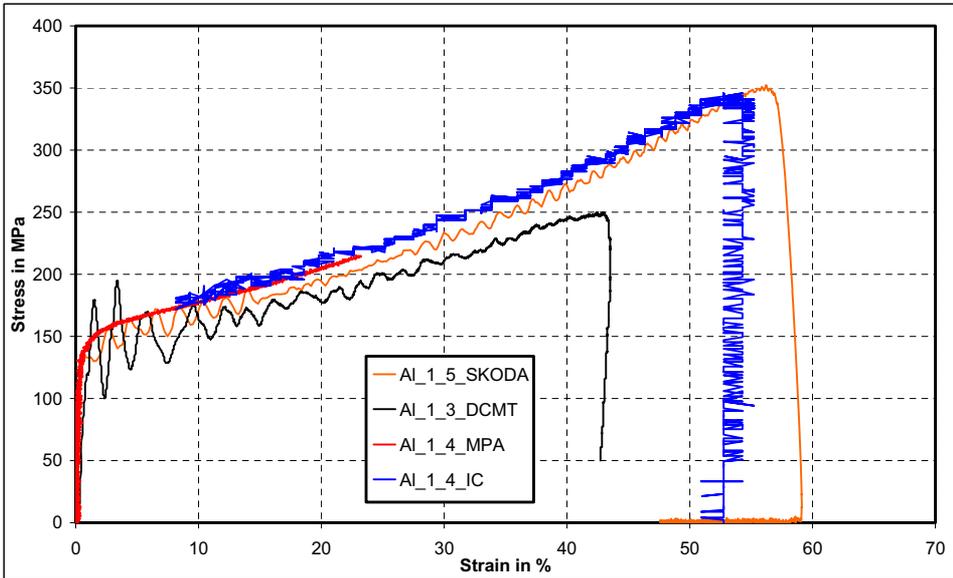
Fig. 6. Comparison of test records obtained by all participants – Al_1 alloy
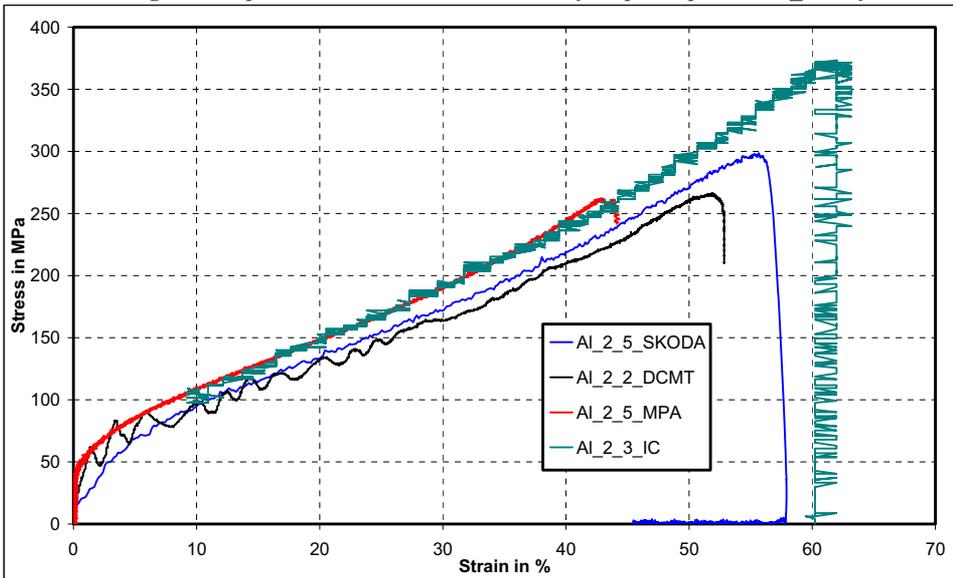
Fig. 7. Comparison of test records obtained by all participants – Al_2 alloy
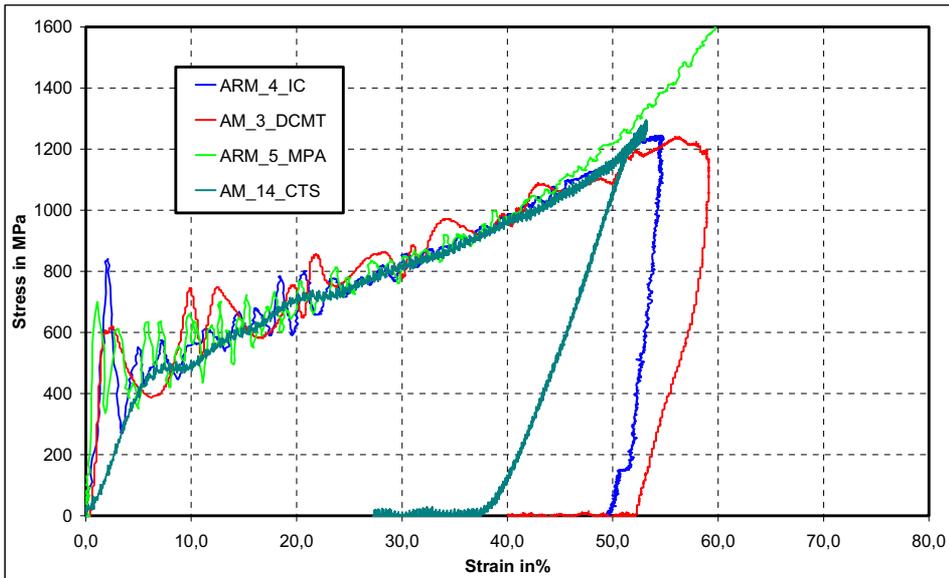
Fig. 8. Comparison of test records obtained by all participants – ARMCO steel

Conclusions

The results of two round-robins of dynamic compression tests were performed within the framework of the ESIS TC5 group are presented here. Five laboratories from three European countries took part in the testing program. Three of the most common types of testing machines employed here are: Drop Weight Tower, Charpy Impact Pendulum and High Speed Servohydraulic Machine. Loads were measured by strain gauge based as well as piezocrystal based loadcells. Specimen deformation was also determined by a range of methods: LVDT, Digital optical read head, inductive gauge and integration of force vs. time data. Thus relatively wide ranges of tests variables were included into the current tests.

The materials investigated were two states of 1050 Al-alloy and Armco iron. The first round of tests on Al-alloy proved comparability of results obtained on various testing systems. Some slight offset was noted in the force levels obtained and there were some differences in the slopes of the curves at small strains. The discrepancies in the forces gave a hint that calibrations are required to be checked, which was done prior to second round of tests.

The second round of round robin tests performed on Armco iron confirms the close comparability of dynamic compression tests performed by all participants. Excellent agreement of curves, at strains above 5%, was obtained by all participants for this stage. A check of the calibration parameters proved to be a good recommendation. Differences in the curves at strains below 5% are most likely to come from dynamic responses of the systems and the machines used; modification of this is rather complicated, but still possible in the future.

Compression tests are generally used for determination of material plastic behaviour and the results presented clearly show the applicability of dynamic compression testing for these purposes. Moreover, comparison of results obtained with different machines clearly show that useful results can be obtained on testing systems from different price levels.

On the basis of the results, it is proposed that a standard procedure for dynamic compression test is prepared.