1. Introduction

The impact testing of structural materials has received an extensive attention recently, because it takes into consideration the effect of high strain rates that has substantial effect on material mechanical properties in many cases, makes it possible to use relatively small test specimens which can be very often withdrawn of components in service and, last but not least, the mechanical properties at compression loading are rather often case in practise, e.g. in the automotive industry and virtual testing of crash situations.

The usual practise today is to perform these (compression testing at impact) tests by means of drop-weight towers or “quick” servo-hydraulic test systems. The first ones do not often belong to the most frequent equipment of testing laboratories, the hydraulic testing machines commonly represent a rather expensive investment and thus they do not belong to the current laboratory equipment as well.

On the other hand, the Charpy impact pendulum test machines are used in many mechanical testing laboratories all over the world and for the purposes of impact compresion testing they only need to be instrumented, what really exists in numerous cases, because the instrumented and already standardized Charpy tests belong often to common experimental practise in many laboratories together with the dynamic fracture toughness testing.

To be able to perform impact compresion test on an instrumented Charpy pendulum machine, structural alterations were realised which consisted in a stop-block design of pendulum movement and a striking tup change. By means of these simple and inexpensive alterations, the impact compresion tests can be carried out, which were proved to be in a very good agreement with the other abovementioned testing machines.

For the purposes of this test method validation, an international round robin was launched within the frames of ESIS Technical Committee No.5, SC on “Mechanical Testing at Intermediate Strain Rates”.

2. Charpy pendulum test machine alterations

The common Charpy pendulum testing machine, having been instrumented for the purposes of instrumented tests of Charpy V-notched test specimens, was used for the impact compresion tests. The necessary structural alteration consisted in

- a stop-block, which serves as a support for the test specimens. This was designed to be sufficiently tough and be able to hold additional plates of top hardness and variable thickness what makes it possible to adjust the striking cross section plane of test specimens so that they were parallel to the striking edge of the pendulum at impact in case of different test specimen lengths,
- manufacturing of a flat tup striking plane instead of the rounded one which is used for the common Charpy testing.

The other parameters of Charpy pendulum testing machine were kept unaltered because the recording test chain could be used in the same manner it is used for other impact instrumented Charpy tests.

The Charpy pendulum which was used for the compresion impact tests and the detail of pendulum striking tup and specimen positioning is shown in Fig 1.

![Charpy pendulum and the detail of pendulum tup and specimen positioning](image)

2. Impact Compresion Testing

The basic record of the dynamic compresion tests is represented by a force-displacement curve, see e.g. Fig.2. Whereas the force can be relatively exactly measured by means of the instrumented tup, the displacement can be evaluated by means of an additional transducer
which measures the pendulum path, or by time measurement of the event and following multiply integration on the basis of Newton’s law when the mass of pendulum and the force are known in any point of the load-time record.

![Fig.2. An example of dynamic compression test record](image)

The system of the test progress recording used in the Mechanical Testing Lab. of the Skoda Research Inst. Is based on the load-time record and the following multiply integration to obtain the force-specimen deformation record. The validation of the method was verified by means of the similarity between Charpy impact tests and the dynamic compression tests. In the course of the classical Charpy tests, the absorbed impact energy is evaluated either of the pendulum energies difference before and after the impact or by integration of the area below the force-displacement(bend) curve after the specimen fracture.

If the calculated deformation is correct then the energy values evaluated by means of the abovementioned procedure should be in agreement with energy values at the pendulum dial. The respective measurements were performed for several levels of energy up to 170 J. The results in Fig.4 reveal a slight systematic deviation of the calculated and measured values, nevertheless, this deviation seems to be acceptable with respect to the complexity of recording chain and evaluatiuon procedure. It can be thus concluded that the evaluation algorithm is correct.
Another prove of the deformation evaluation correctness was obtained on the basis of own dynamic compression test records, where the resulting final deformation/compression of test specimens was compared with the exact measurement of test specimens length before and after the tests, see Fig.3. Also in this case, a very good agreement was found among the measured and the calculated values of specimen deformation, the deviation was approximately only 4% in average.

![Fig.3. Comparison of measured and calculated values of deformation](image)

![Fig.4. Comparison of measured and calculated values of energy](image)

The following step during the measurement methodology development was to verify the effect of circular path of the pendulum on the measured values in comparison with the linear movement of loading elements in case of drop-weight towers and servohydraulic test.
machines. The performed calculation revealed that the differences in deformation in case of used test specimens and pendulum geometry do not exceed 0.03 mm. The geometry changes of test specimens cross section were measured after the tests, as well, nevertheless no deviations of circularity were observed. On the basis of the abovementioned calculations and measurements and also with respect to the obtained results in comparison with the results of other laboratories, it can be concluded that the circular path of the pendulum has no significant effect on the dynamic compression test results obtained by means of Charpy pendulum. The examples of obtained load-compression curves are shown in Figs. 5 and 6.

The following step in the development of the dynamic compression test methodology consisted in the international round-robin, which has been organized within within the frames of ESIS Technical Committee No.5, SC on “Mechanical Testing at Intermediate Strain Rates”.

Fig.5. An example of the dynamic compression test record of a steel specimen

Fig.6. An example of the dynamic compression test record of an Al-1050 alloy
The participants of the round-robin were: SKODA Research Ltd. Pilsen, CZ, Imperial College, London, UK, Royal Military College of Science, University of Shrivenham, UK, and MPA Stuttgart, GE.

Within the frames of the interlaboratory round-robin, the following test equipments were used:

- Drop-weight tower (RMCS Shrivenham, IC London, UK)
- Instrumented Charpy pendulum (SKODA Research Ltd., CZ)
- Servohydraulic test machine (MPA Stuttgart, GE)

Test conditions of individual laboratories are summarized in Tab.1.

### Tab. 1 Test conditions in individual laboratories

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Specimen</th>
<th>Mass of striker</th>
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<th>(v_f)</th>
<th>Lubricant</th>
<th>Strain</th>
<th>Strain rate</th>
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<tr>
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Experimental material, Al-Alloy Al-1050 test samples, were tested after two heat treatment modifications. This alloy was chosen because of its minimum deformation strengthening. The alloy was cold-rolled without inter-operational annealling and additionally heat-treated. One half of the material was annealled at 600degC/10min followed by cooling in furnace to 350degC. This heat treatment resulted in complete recrystalisation and a regular fine-grained structure. The other part of the material was left in the state after rolling without any heat treatment.
3. Tensile to rupture test results of the Al-Alloy

The tensile to rupture tests were performed at the Mechanical Testing Laboratory of the Skoda Research Inst. by means of ZWICK 250 kN testing machine acc. EN 10002-1. The results are demonstrated in Fig. 7.

Results:

<table>
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<tr>
<th>Nr</th>
<th>Designation</th>
<th>Diameter d₀</th>
<th>S₀</th>
<th>E</th>
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<th>Rm</th>
<th>Ag</th>
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<td>76.73</td>
<td>29.62</td>
<td>47.98</td>
<td>85.1</td>
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</table>

Series graph:

Fig.7. Tensile to rupture test results of the Al-Alloy
4. Dynamic Compression Test Results

Fig. 8. Dynamic compression test results of SKODA, variant 1

Fig. 9. Dynamic compression test results of SKODA, variant 2
Fig. 10. Overall comparison of the dynamic compression test results, Al-Alloy, variant 1

Fig. 11. Overall comparison of the dynamic compression test results, Al-Alloy, variant 2
Conclusions

1. The instrumentation of the Charpy pendulum proved the real possibility to perform the dynamic/impact compression tests.
2. The cooperation realised within the frames of the ESIS TC-5 SC committee made it possible to verify and validate the results obtained at the SKODA Research Inst.
3. The results obtained at SKODA are fully compatible with the results of other test laboratories that used different types of testing devices.
4. The temporary results proved the realistic possibility of the standardization of test methodology irrespective of testing equipment (Charpy pendulum, Drop-weight Tower, Servo-hydraulic Testing machine).

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