Simulation of the Drop Impact Behaviour of Metallic Hollow Sphere Structures

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Summary:

Metallic hollow sphere structures (MHSS) form a new group of advanced composite materials characterised by high geometry reproduction leading to stable mechanical and physical properties. The MHSS combine the well-known advantages of cellular metals in terms of their high ability for energy adsorption, good damping behaviour, excellent heat insulation and high specific stiffness without major scattering of their material parameters. Combination of these properties opens a wide field of potential applications, e.g. in automotive (crash absorber) and aerospace industry (sandwich panels). Various joining technologies such as sintering, soldering and adhering can be used to assemble single metallic hollow spheres to interdependent structures and allow to adjust different macroscopic properties.

In this study, reliable drop-weight impact simulations for MHSS plates are carried out and the influence of different material formulations is investigated. The numerical results of the low velocity impact testing based on a dropping steel cylinder form the basis for the design of an appropriate experimental realisation.

Keywords:

Metallic Hollow Sphere Structures (MHSS), Cellular Metals, Drop Test, Finite Elements

1 Introduction

The concept of porous and cellular metals first emerged in the beginning of the 1970s [1-3]. The basic idea seeks to imitate the cellular structure of high performance lightweight structures in nature such as the human bone structure and can therefore be related to the field of bio-inspired research. Nowadays, especially foams made of polymeric materials are widely used in all fields of technology. For example, Styrofoam® and hard polyurethane foams are widely used as packaging materials. Other typical application areas of polymeric foams are the field of heat and sound absorption. During the last few years, techniques for the manufacturing of novel cellular and porous metals have been developed [4,5]. These materials exhibit a high potential for future oriented multifunctional applications due to their specific properties.
Well-known advantages of cellular metals are their high ability for energy adsorption [6,7], good damping behaviour [8,9,10], sound absorption [11], excellent heat insulation [12,13] and a high specific stiffness [14,15]. The combination of these properties opens a wide field of potential applications, e.g. in automotive, aviation or space-industry [16]. However, despite more than 30 years of intensive scientific research few industrial applications of these technologies can be found. Essential limiting factors for the utilisation are unevenly distributed material parameters [7] and relatively high production costs. Less variation in the physical properties can be achieved with lattice block materials [17]. These structures are manufactured by investment casting and therefore exhibit a well defined, reproducible geometry (periodic 3D truss structure). Limitations are high costs, limitation to open celled structures and anisotropic properties caused by the microstructure orientation.
Metallic hollow sphere structures (MHSS) form a new group of advanced composite materials characterised by high geometry reproduction leading to stable mechanical and physical properties. The MHSS combine the well-known advantages of cellular metals without major scattering of their material parameters. Various joining technologies such as sintering, soldering and adhering can be used to assemble single metallic hollow spheres to interdependent structures and allow to adjust different macroscopic properties [18,19,20].
The application of these new materials requires constitutive equations which are based on and verified by appropriate experimental techniques. Common test setups to investigate the impact behaviour are the split Hopkinson pressure bar [21,22] or a drop weight impact test [23]. First investigations of MHSS under impact conditions were carried out in [24].
This paper has a focus on the energy absorption behaviour of adhesively bonded hollow sphere structures. A simple testing facility to analyse the energy absorption for standard specimens is a drop tower. A numerical simulation of a drop test helps to define a real testing facility. The overall objective is to define all relevant parameters before this test bench is designed and built. Those parameters could either be geometrical dimensions of the test bench or basic material data of the MHSS like Young's modulus and plastic yield behaviour, which are seen as parameter in this context.

2 Metallic Hollow Sphere Structures (MHSS)

The absorption behaviour of a MHSS is assumed to be influenced by its structure. This is characterised by

- geometrical dimensions of the spheres (diameter, thickness),
- material of the spheres,
- connection between spheres (e.g. adhesively bonded, sintered, soldered),
- assembly of spheres in the 3D structure (e.g. primitive cubic, body centered, face centered or hexagonal).

For our investigation we make the following assumptions: The geometrical dimension of every sphere is the same. Diameter and thickness are constant (see Fig. 1). The outer diameter of a sphere is 2 mm, the wall thickness is 0.2 mm, the width of the interconnection is 0.7 mm and the overall dimension of a single unit cell is 2.24 mm. In the FE- Model, linear 3D solids are used. Fig. 2 shows the mesh for a single sphere.

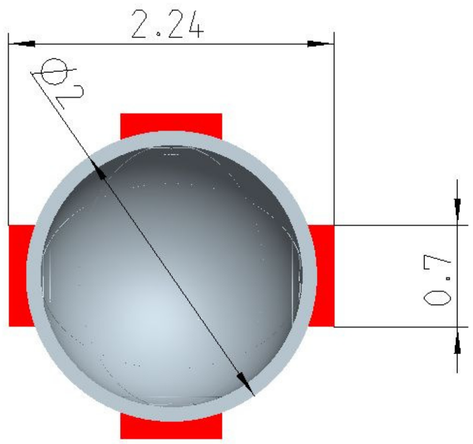

Fig. 1: Geometrical dimensions of a sphere with interconnection

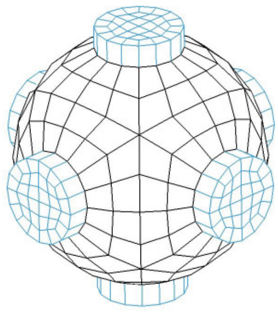

Fig. 2: FE-model of a single cell

The assembly of spheres in the 3D structure is in a primitive cubic pattern, distances between spheres are constant in any direction. Figure 3 shows an assembly with 27 spheres.

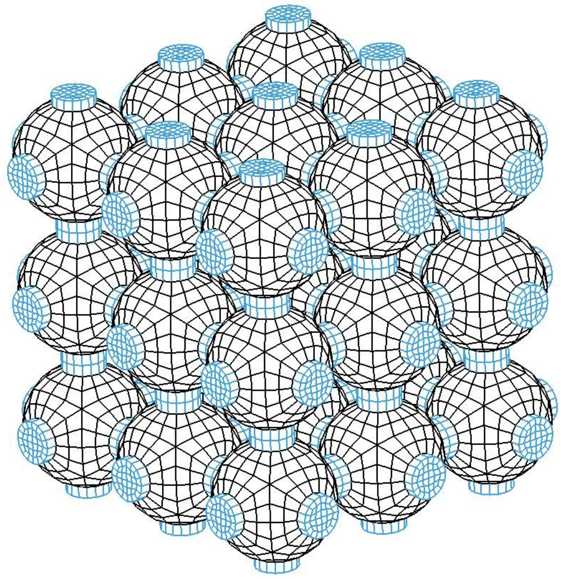

Fig. 3: Regular assembly of spheres as a 3D structure in a primitive cubic pattern

3 Numerical Simulation

With the help of numerical simulation it is possible to analyse a broad spectrum of variants. In the following section the results are presented for some parameters in the “system” MHSS. For the simulation of the compression test as well as the drop test the explicit FE-program LS-DYNA is used.

3.1 FE-Model

In order to check the influence of the FE-model three different levels of detail are defined. A coarse model with 384 elements, a medium sized model with 1360 elements and a fine model with 2645 elements for a quarter of a single cell are in use (see fig. 4). For all simulations a linear element formulation is used.

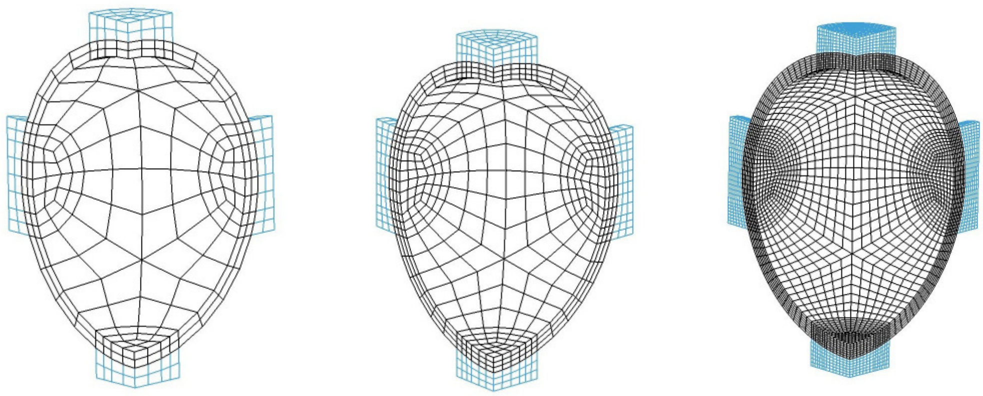

Fig. 4: FE-Model with a coarse, a medium sized and a fine mesh

3.2 Quasi-static behaviour

Initially the quasi-static behaviour under uniaxial loading conditions is discussed. A single cell, placed on a fixed plate, is loaded with a displacement controlled punch (Fig. 5). Symmetrical constrains are applied.

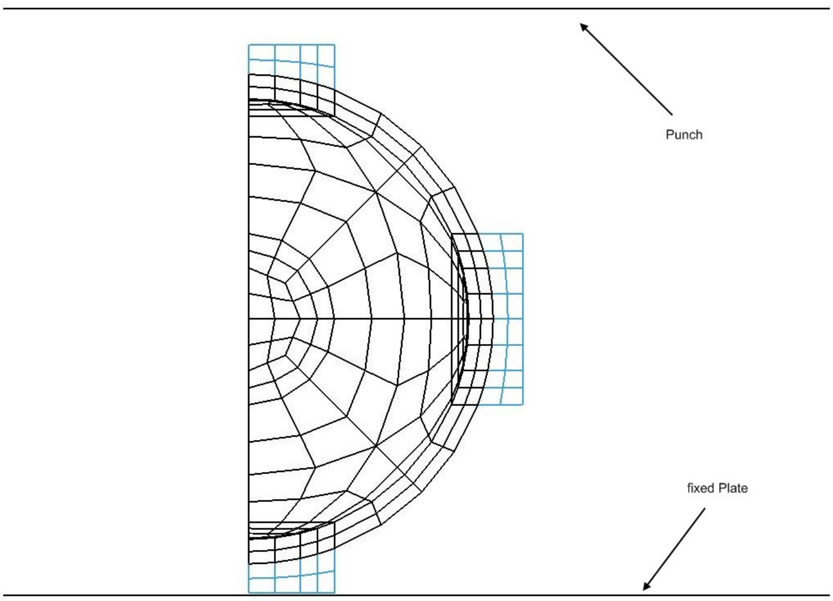

Fig. 5: Initial configuration

The material properties of the spheres are defined by a Young's modulus of 110000 N/mm^2 and a Poisson’s ratio of 0.28, the properties for the adhesive (epoxy resin) are 3500 N/mm^2 for the Young's modulus and 0.3 for Poisson’s ratio. The plastic yield is 210 MPa resp. 70 MPa.

In figures 6a and 6b the deformation is plotted for a standard load with and without failure of the adhesive. In fig. 7 a force-displacement diagram is seen for variations in mesh size and failure criteria of the interconnection.

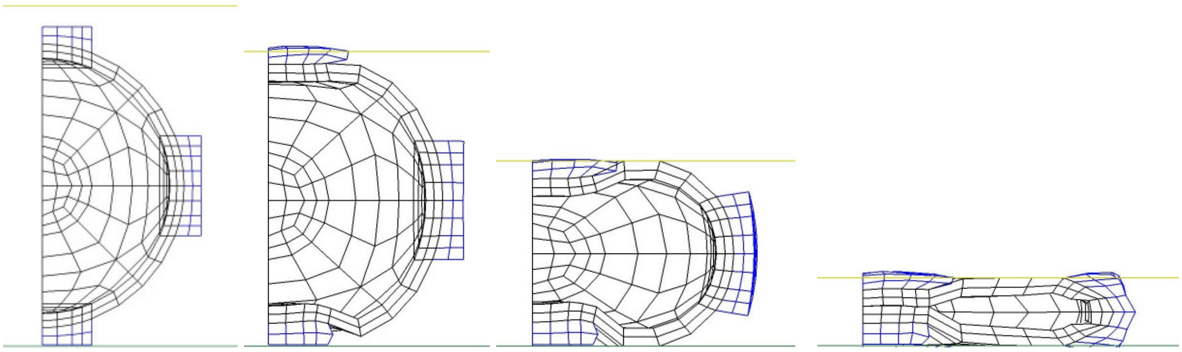

Fig. 6a: Deformation of the structure without failure of the adhesive

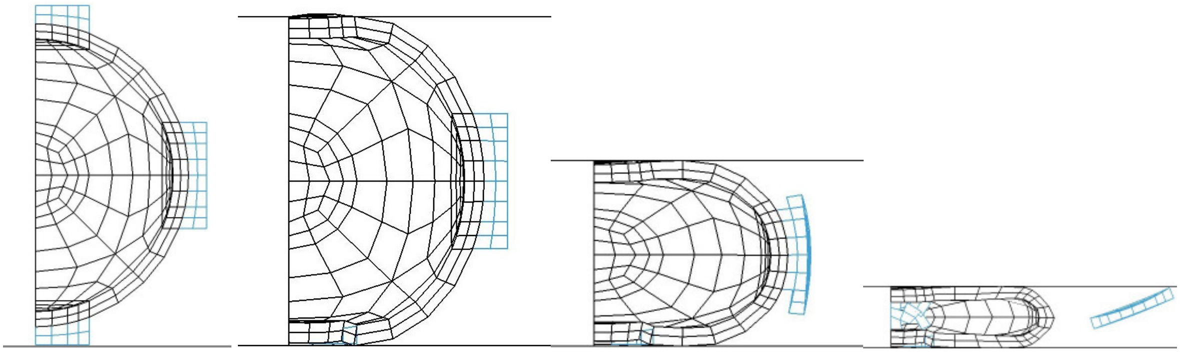

Fig. 6b: Deformation of the structure with failure of the adhesive

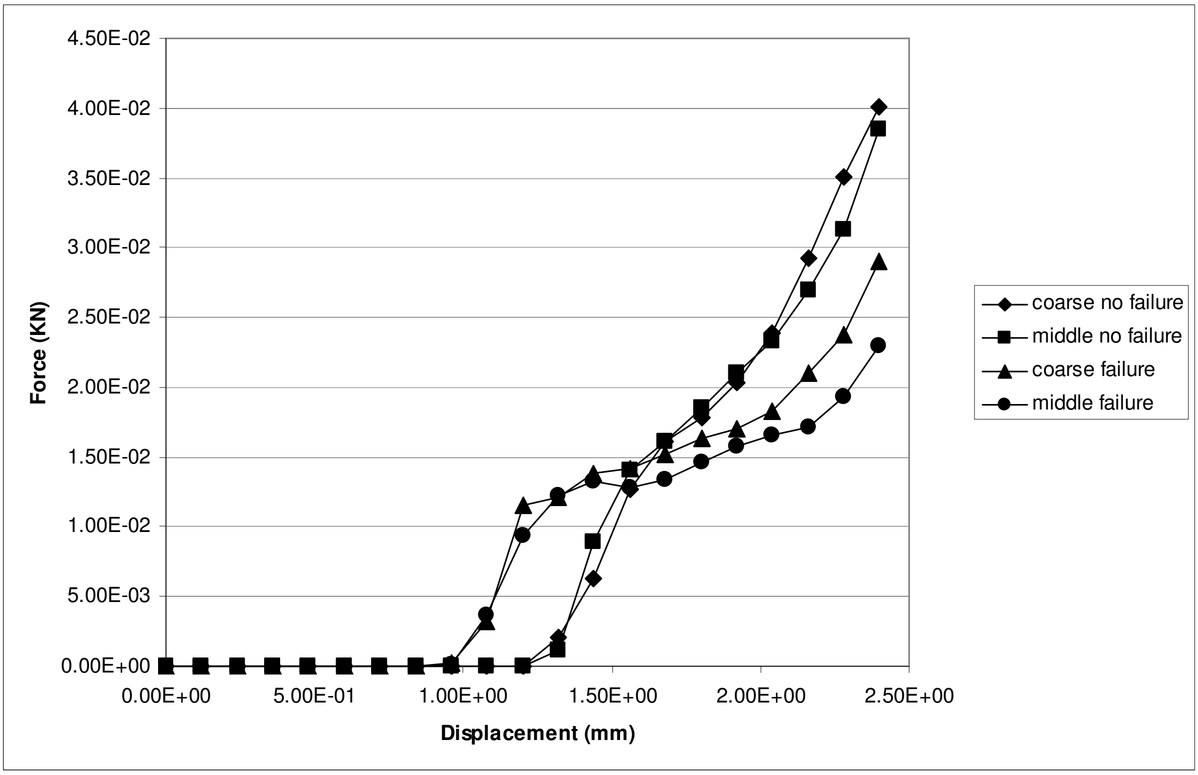

Fig. 7: Force-displacement diagram for different levels of mesh size and failure criteria.

In Fig. 7, the zero force up to a displacement of about 1.5 mm results from the fact that there is an initial gap between the moving rigid plate and the specimen.

3.3 Impact behaviour

The dynamic behaviour of the MHSS will be analysed by a drop test. It is assumed that a punch impacts the structure at a velocity of 5 m/s. The test specimen is a 3x3x3 cell structure consisting of 27 cells. Fig. 8a shows the test configuration. A cylindrical rigid punch impacts a test specimen which is fixed at the bottom nodes. The direction of impact is the global z-direction. Fig. 8b shows the top of the cell structure (global x-y-plane).The test specimen has fixed constrains in normal directions at the four surrounding planes (y-direction for x-z-planes and x-direction for y-z-planes).

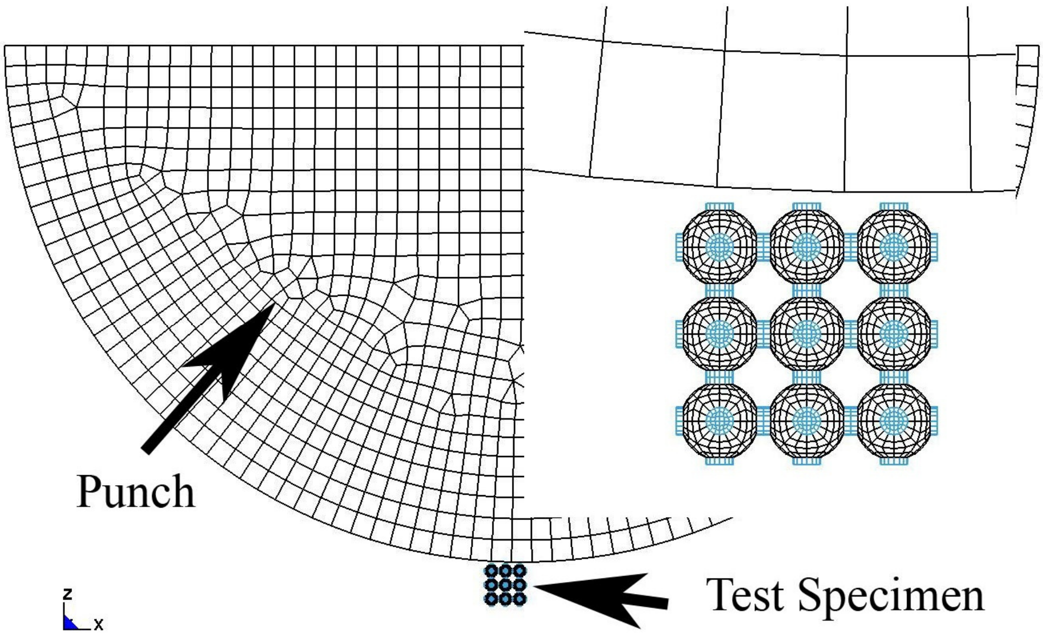

Fig. 8a: Test configuration

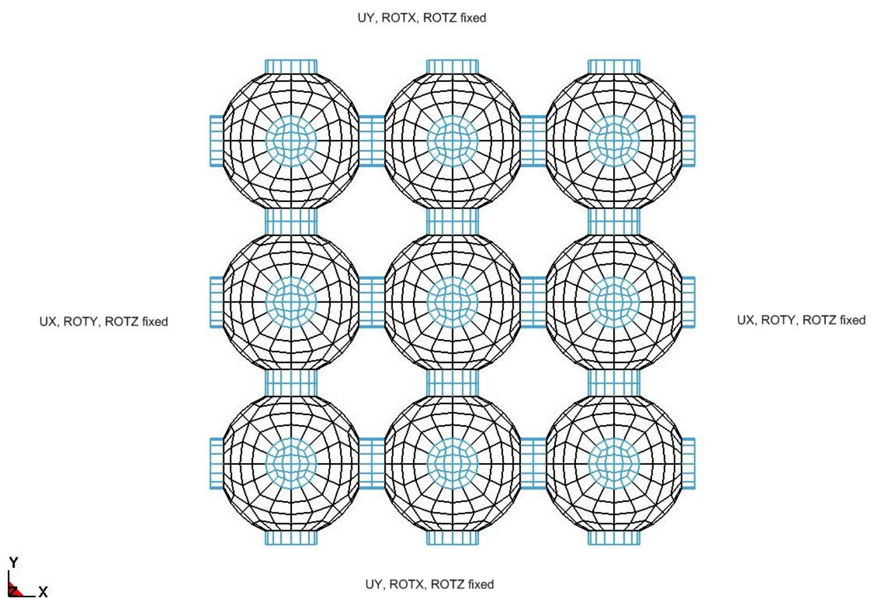

Fig. 8b: Constrains

In fig. 9 the deformation after impact is shown.

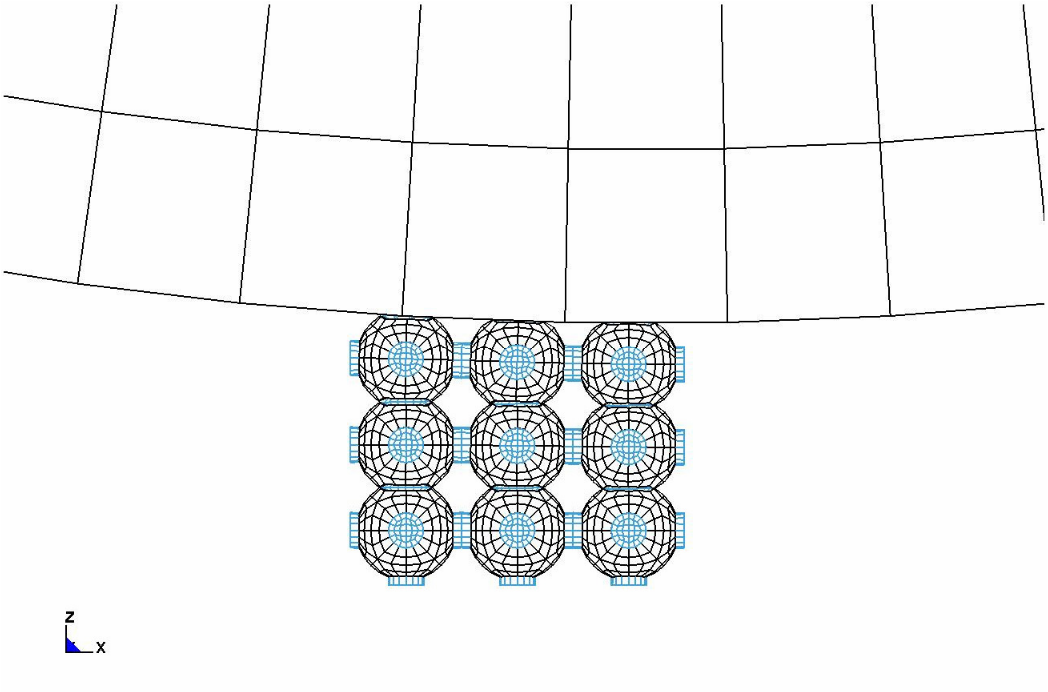

Fig. 9: Deformation after impact

The simulation is done with different material types available in LS-DYNA, different friction coefficients, with and without failure of elements. Tab. 1 shows the characteristics and the input parameters of the considered material types. Coulomb's law is used to describe friction between punch and cell structure. The failure criterion for the adhesive is the plastic failure strain.

Material Type	**Characteristics**	**Input Parameter**
MAT03	Plastic	Young's modulus, Yield stress, Tangent modulus
MAT12	Elastic-Plastic	Shear modulus, Yield stress, Tangent modulus
MAT13	Elastic-Plastic with failure	Shear modulus, Yield stress, Tangent modulus, Plastic failure strain
MAT24	Elastic-Plastic	Young's modulus, Yield stress, Stress-strain curve

Tab. 1: Material Types

In figure 10 the displacement of the punch is plotted for different material types. Figure 11 shows the displacement for failure criteria at different plastic strain values and figure 12 for different friction coefficients. Fig 13 shows the energy absorption for different material types.

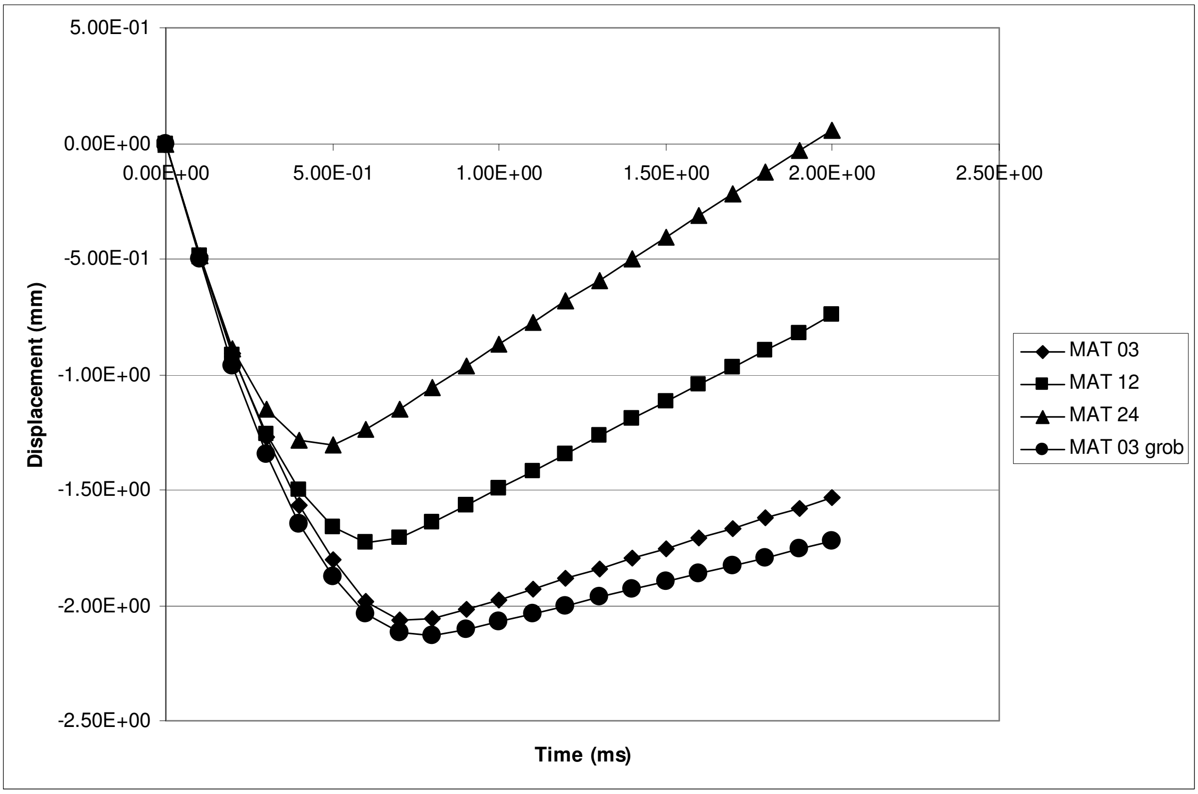

Fig. 10: Displacement for several material types

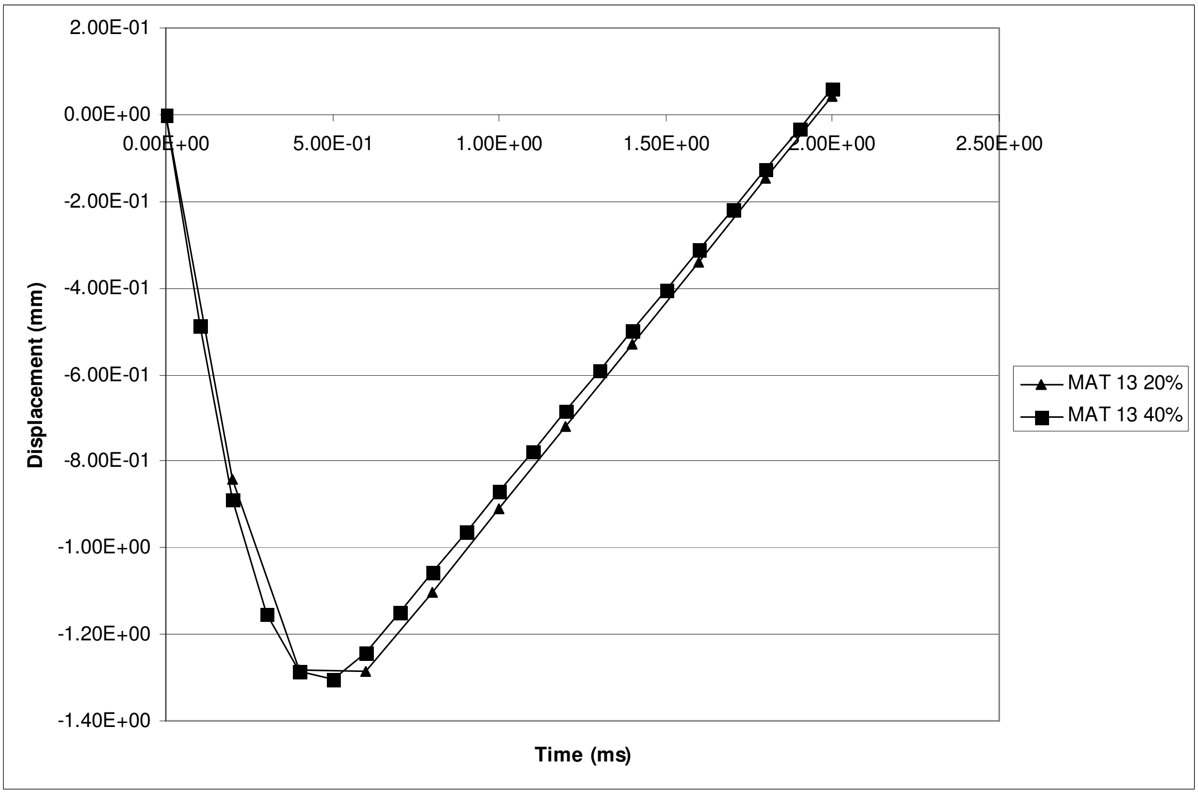

Fig. 11: Displacement for different values for the plastic failure strain

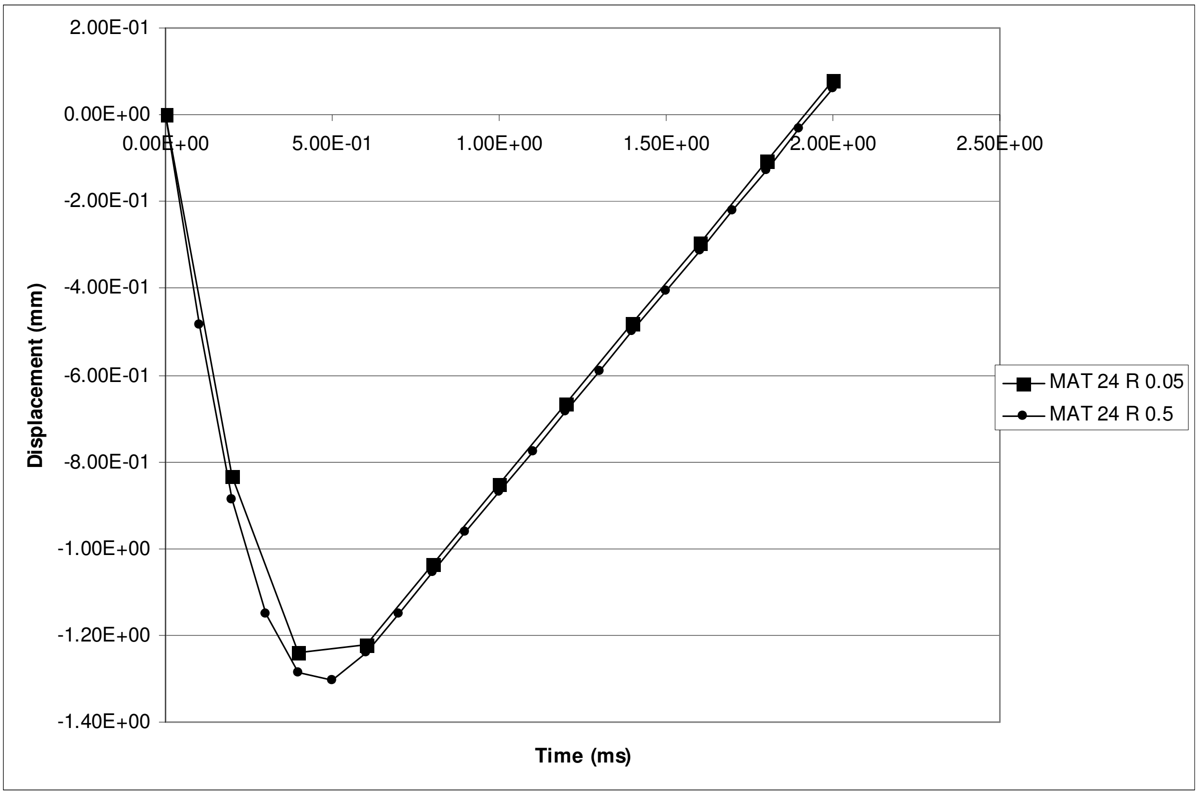

Fig. 12: Displacement of the punch for several configurations

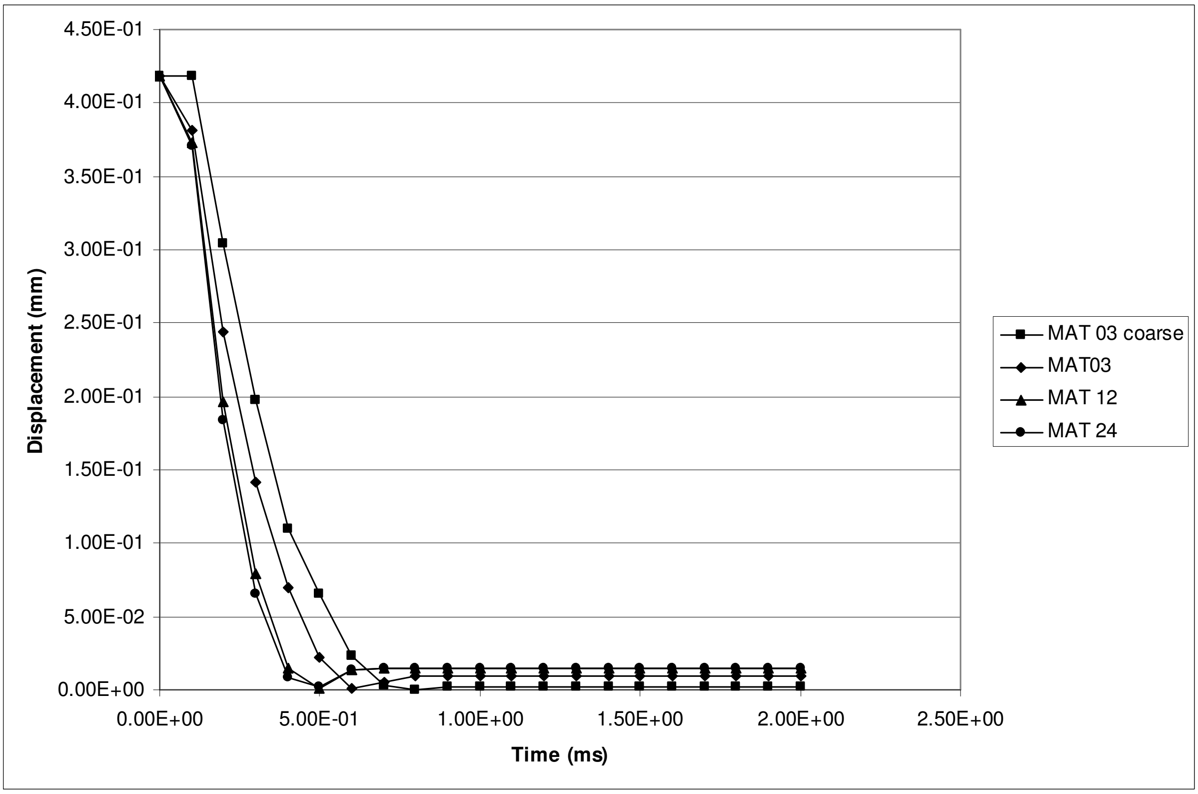

Fig 13: Energy absorption of the structure for different material models

4 Summary

In scope of this study, a computational finite element model for a drop-weight impact test with metallic hollow sphere structures has been developed. The structure itself has been composed of 27 single spheres and different material models were applied to the MHSS. It could be shown that the materials formulation, i.e. material model, failure model of the adhesive and the frictional conditions between the impacter and the sphere structure can have a significant influence of the computational results.

The simulations help to design proper test equipment for the physical compression and drop test. Force and acceleration sensors, recording equipment and dimensions of the test machines can be chosen.

5 Literature

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