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Withstanding capacity of insulating panels used in machinery assemblies.

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In assembly of machinery and production lines, it is, sometimes, possible to isolate workers from noise and other emissions by cabin and walls built with polyurethane core.
Wall sheet sandwich panels with insulating core in polyurethane foam, used for the construction of infill walls, internal partitions and false ceilings of buildings and prefabricated construction sites are a common solution for this aim.
These panels, having an external sheet in aluminium, steel or other materials are also able to protect workers from temperature, coolants, and swarf but they are usually not designed in order to protect against impacts due to ejections of workpieces or tool parts.
Even if the original aim is to protect against the effects of noise, there is a residual risk, especially in machine not fully enclosed by fixed or mobile guards, such as huge machining centres and lathes or woodworking machines.
In this paper, the withstanding capability of either a single or two coupled (double) sandwich panels, made as previously described, will be investigated. In addition, the so-called ballistic limit for these structures will be discussed.
Real protective properties of those insulating panel walls will be presented considering ~~to~~ the requirements indicated in ISO 14120:2015.
Moreover, the stiffening effect in withstanding capability, probably due to rib surfaced outer metallic sheets of panels assembled in multilayer disposition, will be discussed.

Keywords: Machine tools guards, safety of machinery, ejection risk, ISO 14120:2015, safety test.

1. Introduction

Machinery complexity associated with an optimized organization of the space and of the manufacturing process often requires ad hoc solutions for safeguards. The level of performance of the previous safeguards shall be assessed in order to ensure operators' protection from existing risks, see Pera et al. (2021). In some huge assemblies of machinery-full guarding is not generally required by applied standards but other safety issues may be present such as noise, temperature gradients, coolant emissions and swarfs.

Protection against risks related to these issues can be achieved with structures (cabin, walls and ceilings of rooms) realized with sandwich panels made of two (possibly rib surfaced) outer metal sheets and filled with polyurethan foam. They are also used in large machinery assemblies in order to build sound absorbing walls. Anyway, operators can pass freely behind them.
The implementation of these panels is easy because they are designed to be used in a modular way.
They can be overlapped in order to enhance the noise absorbing effect in a multilayer configuration.

If the risk assessment shows that there is a chance that a piece of a tool or a workpiece may be ejected from the machine, then these structures behave like guards and their withstanding capability must be assessed against impacts.

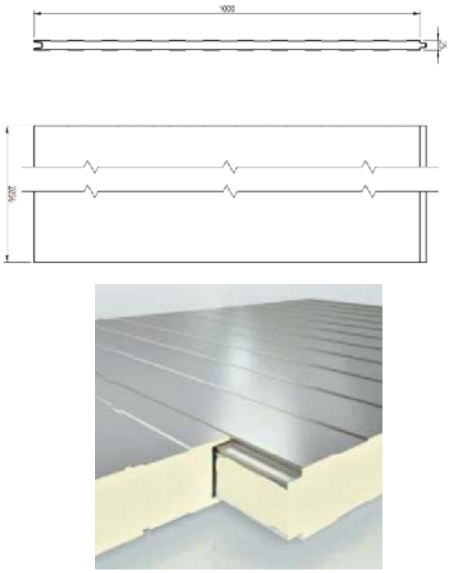

Figure 1: typical noise reducing polyurethane modular panels.

Characteristic of tested panels are in table 1.

2. Requirements and standardization

According to EHSR 1.3.3 of Annex I of Directive 42/EC "Precautions must be taken to prevent risks from falling or ejected objects". More specifically EHSR 1.4.1 states that guards must:

- be of robust construction,
- protect where possible against the ejection or falling of material or object.

In addition, the international type A standard ISO 12100 for machinery risk assessment and reduction specifies at clause 6.3.3.2.1 that containment/capture of materials, workpieces, chips, liquids which can be ejected or dropped by the machine is a function that guards can achieve. General requirements for the design and construction of fixed and movable guards are given in the type B standard ISO 14120, applicable to all machines. In Annex B of this standard a mechanical test method is defined ~~for~~ in order to check guards with a projectile in case an impact hazard exists.

Requirements for practical testing were discussed in two different articles by Landi et al. (2022a and 2022 b).

The test is carried out with a sample of the guard material and a compressed air gun that propels the projectile.

Items defined in Annex B are:

- the shape and mass of the projectile: in those test 100g standardized projectile was used;
- the opening of the sample supporting frame (450 mm x 450 mm);
- the criteria to assess the damage of the sample.

In this case, the insulating panels are 25 mm thick with two external steel metal sheets 0.4 mm thick each filled with a polyurethane foam that assures a certified noise reduction as shown in table 1.

Table 1: Insulating panels characteristic

Property	Value
Mass of panel [kg/m^2]	7.3
Thickness [mm]	25
Steel sheet thickness [mm]	0.4/0.4
Insulation [W/m2K]	0.83

In this paper, the withstanding capability of different configurations of insulating panels will be presented and discussed.

3. Insulating panels tests

INAIL and UNIPG, according to the above considerations, performed ballistic tests in Monteporzio Catone Laboratories (Rome) on samples of the aforementioned panels with the aim to evaluate their withstanding capacity as protective guards for machines.

The single panel testing configuration is shown in Figure 2; test bench is described and calibrated as indicated in Landi et al. (2020).

The constraint of the panel, as depicted in Figure 2, is realized blocking it on every side by compression between front-side and back-side screw-locked plates. Sometimes, especially in double layer configuration, described later, typical woodworking locking tools are added, at least on one corner, to assure the proper locking force.

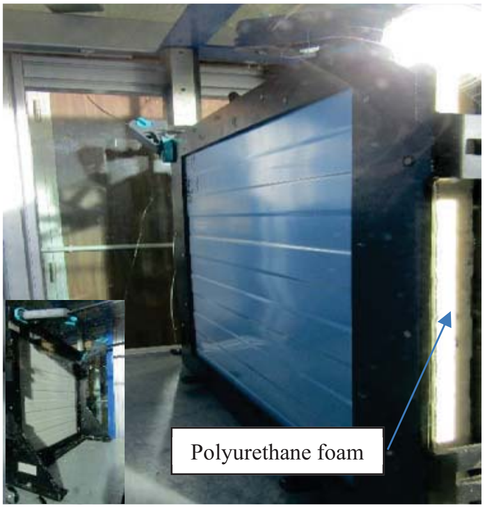

Figure 2: typical test configuration of a single panel, in small picture backside of the panel

The withstanding capability of panels is retrieved using the well know Recht and Ipson (1963) curve. For more specific information about the use of this regression curves see Landi et al. (2016 and 2021).

As already discussed in different paper presented in past by the same authors, a good approximation of ballistic limit can be found at least with five different shots penetrating the target.

Tests are usually performed hitting the centre of the sample as shown in Figure 3.

On Table 2 the typical Recht and Ipson results for the single layer panel is reported. In Table 3 best fit approximation for the curve is shown. The R^2 index in Table 3 states that the obtained regression curve has a good fitting property.

Figure 3: shooting target centre used in standardiza

Table. 2. Experimental data for impact tests on single layer panels

Test	v_i (m/s)	v_r (m/s)	ΔE - energy loss (J)
S1	58.7	47.5	59.4
S2	52.4	36.2	71.7
S3	46.7	22.4	84.1
S4	43.2	18.3	76.5
S5	73.7	67.9	40.9
S6	31.6	N.P.	49.9

N.P. stands for not penetrated – data not used for regression.

Table 3. Best fit parameters for R&I equation, single layer, extremal values of 99% confidence intervals and R^2 values

Parameter	Single panel ~~layer~~
a	1.0
p	2.39
V_{bl} (m/s)	41.3 ± 2.8
R^2	0.98

On figure 4 the experimental data are marked with red crosses and the best fit curve is shown as a continuous black line.

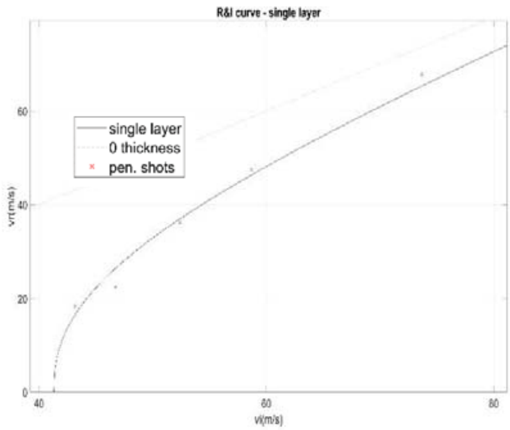

Figure 4: R&I best fit of single ~~layer~~ panel.

As usual the V_{bl} =41.3 m/s velocity is not to be considered as a safe limit for standardization. If the already used reduction factor of 1.3 is used (see Landi et al. 2021) a velocity of 31.8 m/s is obtained. In S6 this velocity was tested and no through crack was observed, so the test is passed for ISO 14120 annex B.

The large dispersion of energy absorbed at different impact velocities is probably due to the polyurethane filling of the panel. With lower impact velocity the panel seems to be more capable to stop the projectile: the polyurethane filling after the impact is expelled through the perforation hole into smaller and smaller parts as the impact velocity increases.

The cohesion between the polyurethane and the metal sheets is very strict, after the impact too. The de-bonding area due to the impact can be measured easily because of the cohesion and is and more or less constant at about 300 mm in diameter.

The typical behaviour retrieved after the impact is shown on figure 5 below.

Figure 5: de-bonding of polyurethane after the impact.

3.1. Double panel configuration

Because of its very poor withstanding capability, a second set of tests is performed. The panels are coupled and closed in the frame with a final thickness of 50 mm, on Fig. 6 two uncoupled panels after the impact are shown.

Because we had some lack of materials, we were able to perform only four shots instead of the typical five. In addition, the impact velocity ranges is tighter than usual. In tables 4 and 5 and in Fig. 7 the result of this test is shown.

Figure 6: double layer panels uncoupled after impact, unperforated second panel (right)

Table. 4. Experimental data for impact tests on double layer panels

Test	v_i (m/s)	v_r (m/s)	ΔE - energy loss (J)
D1	73.6	40.0	190.7
D2	66.3	29.3	177.0
D3	62.2	19.6	174.1
D4	70.1	34.5	186.0

Table 5. Best fit parameters for R&I equation, single layer, extremal values of 99% confidence intervals and R^2 values

Parameter	Double layer
a	0.75
p	2.62
V_{bl} (m/s)	56.6±0.6
R^2	0.99

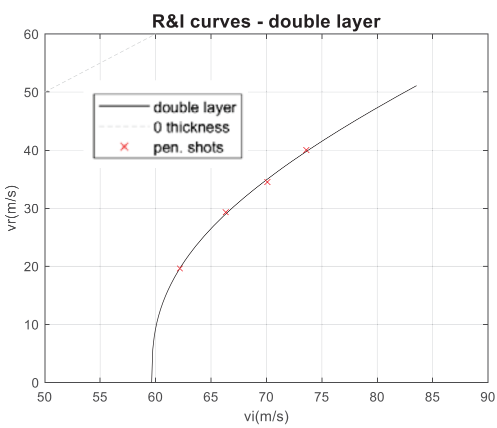

Figure 7: R&I best fit of double layer panel.

The optimization of withstanding capability with multi-layered configurations has been studied since long time. Good references for comprehension of the phenomena are in Corbett et al. 1996 and Teng et al. 2007 where it is also possible to find topics related to the general problem of ballistic performance evaluation of these structures.

In this paper, the energy loss related to ballistic limit (V_{bl}) equal to 41.3 m/s for single layer is 85 J, while the energy loss for double layer is~~,~~ practically doubled at 160 J.

Considering a purely additive behaviour, we can try to simulate the penetration of a double layer through two single penetrations of two separate single layers (see Fig. 8).

So, considering an initial velocity of 73 m/s and the best fit parameters of table 3, the predicted residual velocity is 64.5 m/s (blue line on figure 8.)

Considering a second single panel, uncoupled from the first, and an initial velocity for the projectile equal to the residual velocity above calculated, for the previous impact, the final residual velocity is 54 m/s (green line on figure 8.) The total energy loss for this uncoupled configuration is predicted as 121 J with this simple addition mechanism.

In figure 8 the procedure for the impact considering separate ~~as~~ single layers is presented for clarity.

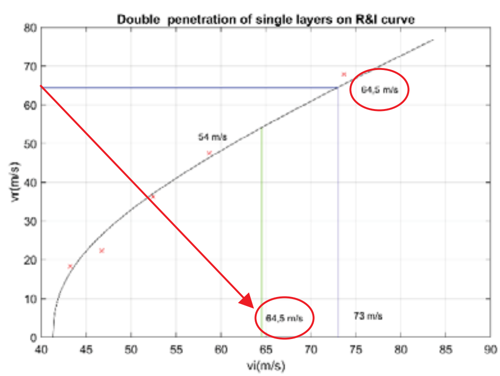

Figure 8: R&I best double penetration of uncoupled single layer

If the same initial velocity of 73 m/s and the best-fit parameters of table 5 is used (real data of double layer), the predicted residual velocity is 39 m/s. In this case, the energy loss is 190 J.

Therefore, the withstanding capability of coupled panels directly clamped one on the other is clearly increased.

A possible interpretation of this behaviour may consider that polyurethane material and steel sheets fragments, derived by the penetration of first layer, make more difficult the penetration of second layer. Moreover, the steel ribs, present on the panel surface, can cause shear effects between the two layers (see figure 9).

Figure 9: ribs present on external steel sheets of panels.

Conclusions

In this paper, authors presented some experimental impact tests on insulation panels sometimes used as local guards in huge machinery assemblies.

Configurations for the test sample was at first with a single panel and then with two panels coupled one on the other (double layer).

Recht and Ipson curve was applied to find the ballistic limit and, in both cases, a nice fitting for the regression curve was obtained demonstrating good quality of the data and the applicability of the method to the specific case.

Considerations made with Recht and Ipson calculation and the determination of the energy losses after penetration, showed a synergic effect between the two-coupled panels in a doubled layer that enhances the withstanding capability compared to the case of two separate panels. Indeed, it is possible that the material of the first layer (polyurethane and metal), through the projectile hole, hinders the penetration in the successive layer. In addition, the steel ribs on the panel (not smooth) surfaces can contribute to this behaviour causing shear effects between the two panels.

Finally it can be noted that energy losses decrease when velocity of the projectile increases.

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