2. CLOSING SYSTEMS COMPARISON

2.1 Machine rigidity

The main difference between a *TF* and a toggle machine is represented by their rigidity. Considering both a structural (e.g. a tie bar or a rod) and a hydraulic component (e.g. a cylinder), the rigidity can be expressed as follows:

$$K = \frac{EA}{L} \quad (1)$$

$$K = \frac{\beta A}{L} \quad (2)$$

where E is the material elastic modulus, β the fluid compressibility modulus, A the utile section and L the component length.

As a consequence, the rigidity referred to a particular system only depends on the system itself and not on external conditions.

Therefore, with reference to a die-casting machine, the casting force resulting from the metal shot has no influence on the machine rigidity: on the contrary, this rigidity can have a certain influence on casting conditions, as shown in the following paragraph.

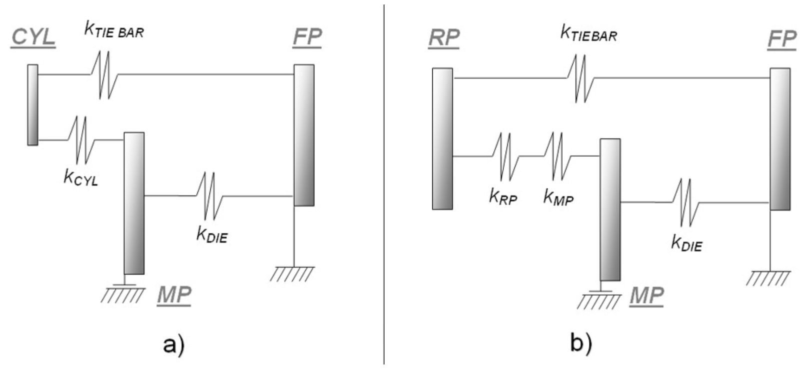

Fig. 7: a) *TF* rigidities; b) toggle rigidities.

Considering the *TF* (Fig. 7a) there are three rigidities, respectively referred to the tie bars (K_{TIEBAR}), the cylinders (K_{CYL}) and the die (K_{DIE}).

Analogously, in a toggle machine there are four rigidities referred to the tie bars (K_{TIEBAR}), the reaction platen and moving platen rods (K_{RP}, K_{MP}) and the die (K_{DIE}).

The machines rigidity can be determined as shown in the equations below:

$$K_{TF} = \frac{1}{\frac{1}{K_{TIEBAR}} + \frac{1}{K_{CYL}}} \quad (3)$$

$$K_{TOGGLE} = \frac{1}{\frac{1}{K_{TIEBAR}} + \frac{1}{K_{RP}} + \frac{1}{K_{MP}}} \quad (4)$$

Calculating for every *TF* machine its rigidity, and comparing it to the equivalent toggle machine (all clamping forces being equal), the difference is remarkable:

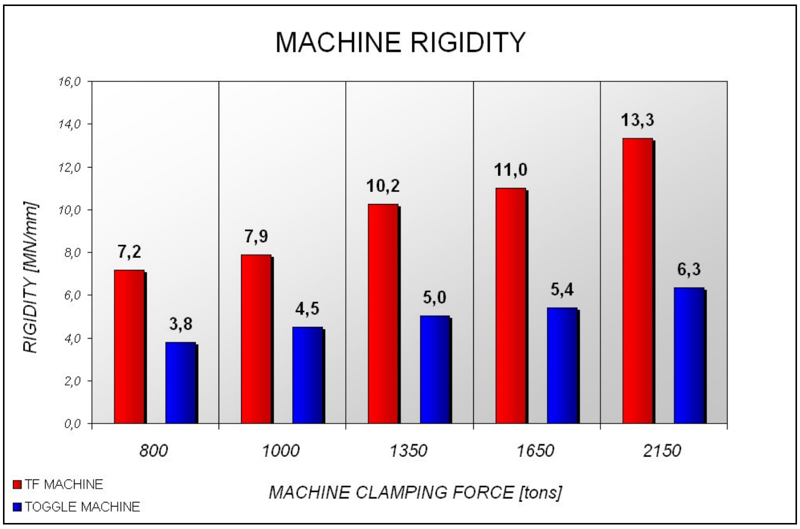

Fig. 8: machines rigidity values comparison.

In fact, the average difference is near to 95%:

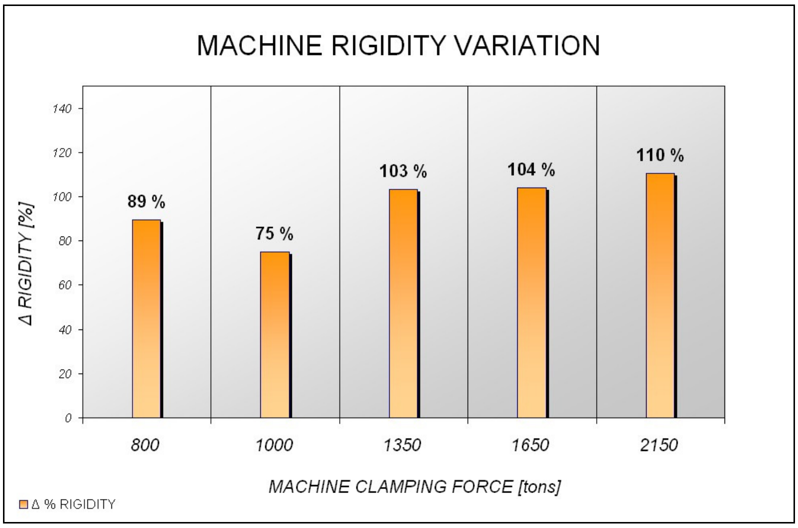

Fig. 9: machines rigidity variation.

2.2 Die compression

Once defined the average dimensions of the die typically used for the considered machine clamping force, it's then possible to calculate its rigidity. As a boundary condition, the external casting force has been established to be equivalent to the clamping force:

$$K_{DIE} = \frac{EA}{L} \tag{5}$$

$$F_{ext} = \text{MACHINE CLAMPING FORCE} \tag{6}$$

As an example, the following figures and charts are referred to a 2150 tons clamping force. The machines and die characteristic curves are represented here below:

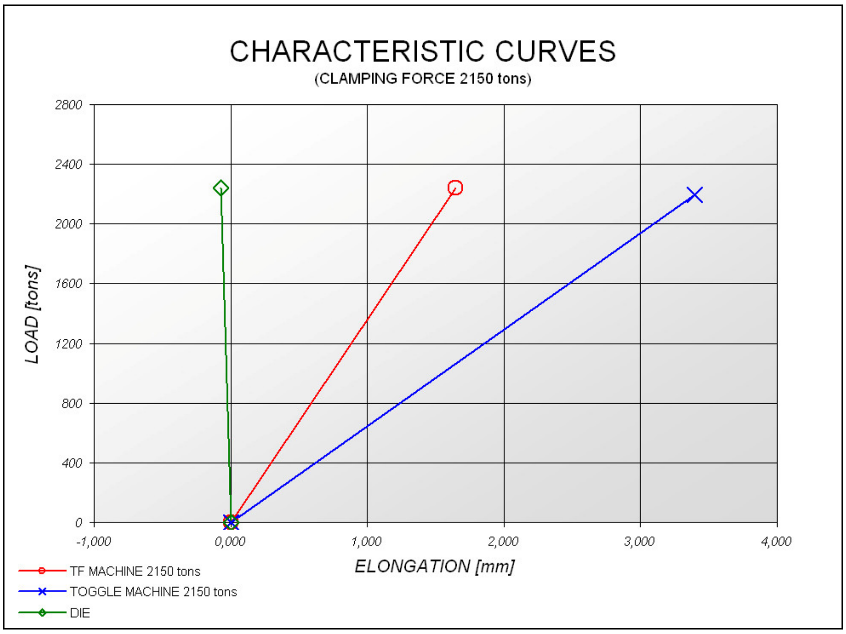

Fig. 10: 2150 tons machines and die characteristic curves.

Considering the preloading conditions, when applying the effective clamping force F_0 (pre-shot phase) the machines are located in two different chart zones. This situation is due to the different curve slopes, which are directly proportional to the rigidity:

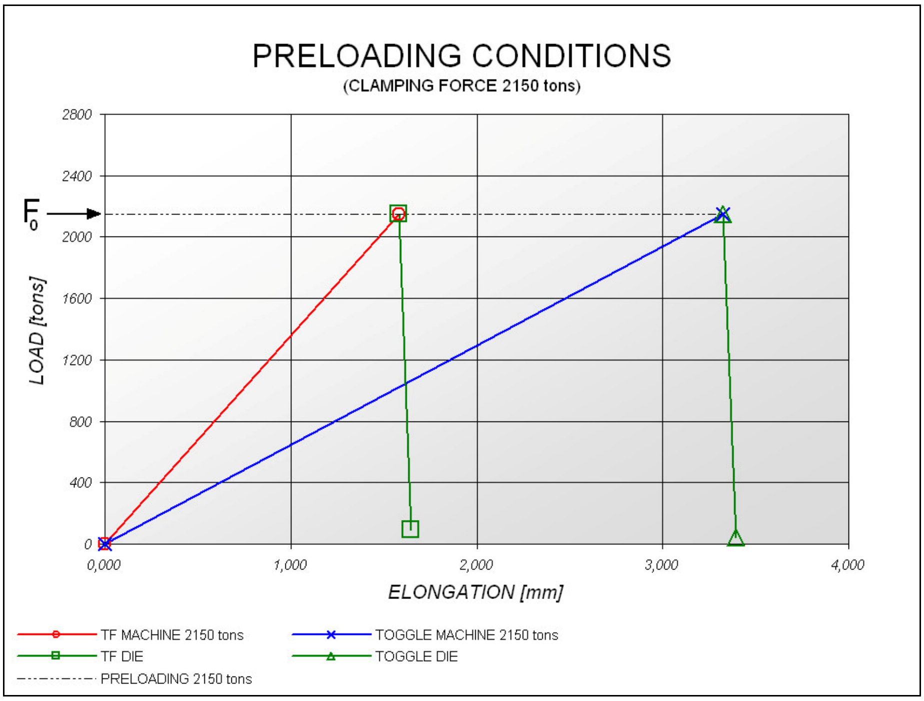

Fig. 11: preloading conditions.

The injection force F_{ext} causes the opening of the die. As a consequence, its compression load reduces whilst the entire closing end is subject to an elongation which can be defined as $\Delta L_{MACHINE}$:

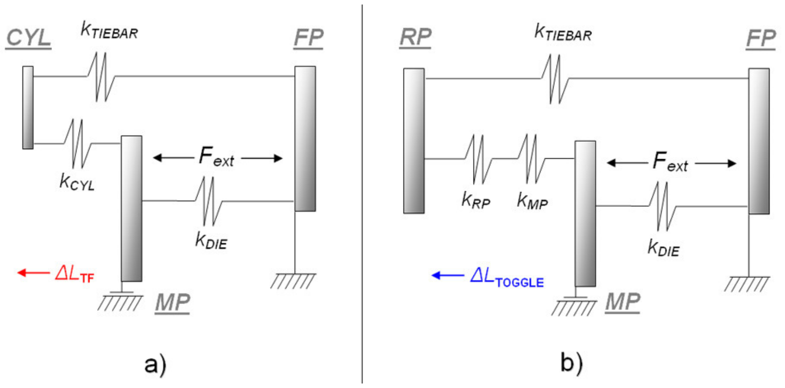

Fig. 12: diecasting effect on rigidities scheme.

Through the congruence equation (7) and the balance equation (8) it is possible to calculate $\Delta L_{MACHINE}$ (9):

$$\Delta L_{MACHINE} = \Delta L_{DIE} = \Delta L \tag{7}$$

$$F_{ext} = K_{MACHINE} \Delta L_{MACHINE} + K_{DIE} \Delta L_{DIE} \tag{8}$$

$$\Delta L_{MACHINE} = \frac{F_{ext}}{K_{MACHINE} + K_{DIE}} \tag{9}$$

The following chart displays the calculations above:

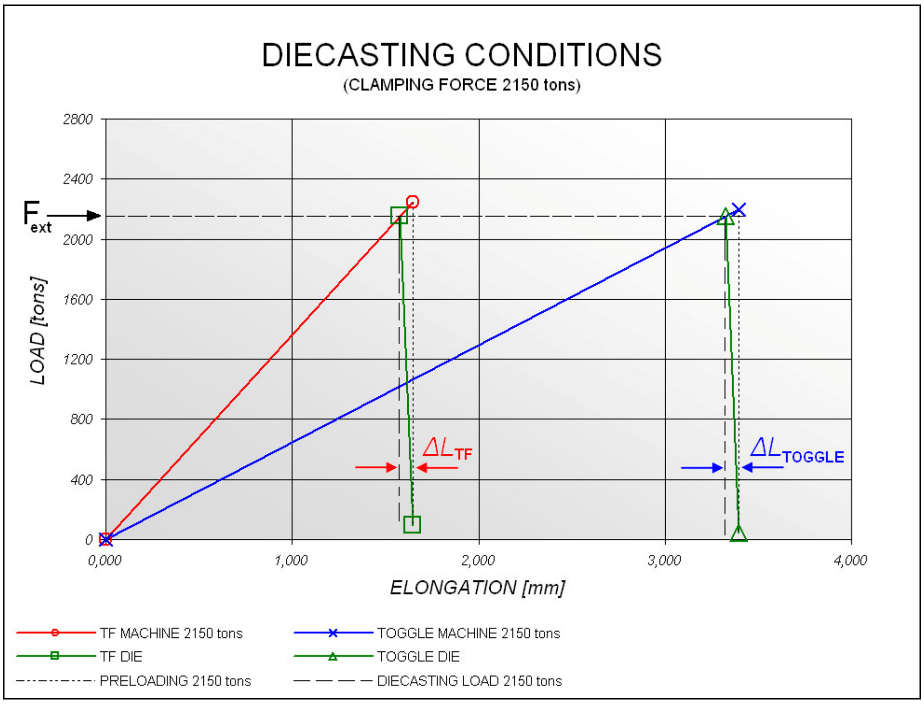

Fig. 13: die-casting conditions chart.

Because of the different rigidity, ΔL_{TF} and ΔL_{TOGGLE} are not the same:

$$\Delta L_{TF} = \frac{F_{ext}}{K_{TF} + K_{DIE}} \tag{10}$$

$$\Delta L_{TOGGLE} = \frac{F_{ext}}{K_{TOGGLE} + K_{DIE}} \tag{11}$$

As a result, considering the equation (12) to calculate the final compression load applied on the die and comparing the two machines results, the values found are remarkably different:

$$F_{DIE_{MACHINE}} = F_0 - K_{DIE} \Delta L_{MACHINE} \tag{12}$$

$$F_{DIE_{TF}} = F_0 - K_{DIE} \Delta L_{TF} \tag{13}$$

$$F_{DIE_{TOGGLE}} = F_0 - K_{DIE} \Delta L_{TOGGLE} \tag{14}$$

With reference to all machine sizes, the situation is exactly the same: the final compression load in a *TF* die-casting machine is higher if compared to the equivalent toggle machine. These values vary from a few tons up to about fifty tons (Fig. 14). It's interesting to notice that the loads percentage difference (Fig. 15) has the equivalent trend of the rigidities percentage difference (Fig. 9). This means that there's a direct proportion between these two quantities: the consequence is a better die closing during the die-casting process, with an overall cast improvement (e.g. surface finishing, flashes reduction), as confirmed by the die casters who are already using a *TF* machine.

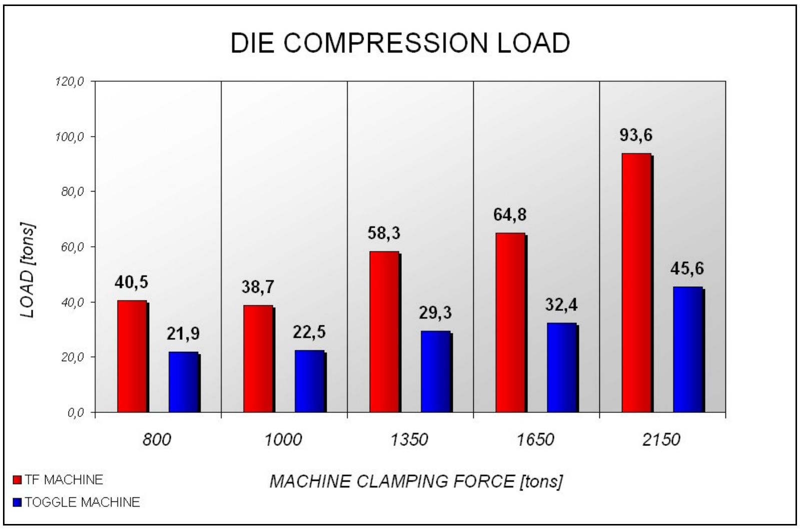

Fig. 14: die compression loads during metal shot.

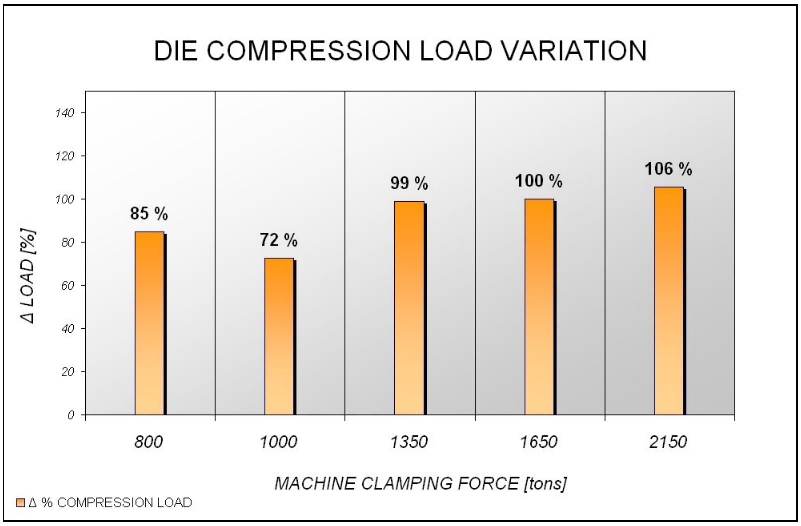

Fig. 15: die compression loads percentage variation.