Sigmund proposed the Solid Isotropic Material with Penalization Method (SIMP Method) for structural optimization. The method consists of discretizing the complete area into small elements. Each of these elements can either be voids or solids. We decide the elemental density changes based on the sensitivities of the elemental densities with the overall structural compliance/stiffness/stress. SIMP is a density-based approach to implementing the topology optimization formulation. The Level set method is another approach to implementing the formulation by representing the 2d/3d boundaries in a higher dimensional function. The higher dimensional function when equals zero represents the boundary between the solid and void region. A very basic difference is the discretization scheme in both cases. In the Level set method, there are multiple discretization schemes available, with the ersatz material approach most closely resembling the SIMP discretization.

As can be seen, SIMP and Level Set Methods are two completely different approaches to topology optimization. The biggest difference between the SIMP and Level Set methods is that the SIMP method alters the material density in elements, while the Level Set method alters the boundary of the solid to change the shape of the structure. This helps overcome the major problem for the SIMP algorithm – an exact boundary. SIMP does not have an exact material boundary, which is available in the Level Set Method.

The original optimization problem includes the discreet nature of material density, which is relaxed in order to be able to formulate an optimization algorithm. The SIMP also included penalization to reduce the probability of an intermediate density occurring. Since the Level Set Methods does not have the issue of intermediate densities, penalization is not required. This helps reduce the non-linearity introduced due to the penalization in the SIMP method and thus, reduces the computational time for the algorithm. Furthermore, if appropriately formulated with regional basis functions, the level set method also provides fast convergence.

The SIMP method uses the sensitivity of the stiffness with the elemental density to decide the addition or removal of material, effectively creating holes in the structure. The Level Set Method uses the shape derivatives of the compliance function and a descent direction using gradient descent to determine the change in the boundary function. Thus, the points can move and can join together, but introducing a new point is very difficult. This leads to a major disadvantage of the level set method. The Level Set method can only merge holes but can’t nucleate new holes from scratch. This adds to the major limitation. This can be removed but then, the complexity of the formulation increases multifold.