



ESCOLA POLITÉCNICA DA UNIVERSIDADE DE SÃO PAULO

Elementos de Máquinas para Automação

PMR 3307 – A25

**Seleção de materiais
e fabricação de engrenagens**

2023.2



Materiais para engrenagens





Materiais para engrenagens

- ▶ **Ferro Fundido:** Menos ruído do as engrenagens de aço inox. Alta resistência à flexão. Boa resistência ao desgaste. Baixo custo.
- ▶ **Aços:** vários (SAE **1045**, **4320**, 4340, **8620**, **8640**, 5140, outros)
- ▶ **Alumínio:** aplicações simples
- ▶ **Bronze:** Material não ferroso.
- ▶ **Polímeros:** *Nylon*—Resistência ao desgaste. Baixo coeficiente de atrito. Baixo ruído. Não necessitam de lubrificação quando a baixas cargas.



Materiais para engrenagens





Equação AGMA

- As equações de Lewis/Barth são a base do sistema AGMA

$$\sigma = K_v \frac{W_t}{F m Y}$$

A metodologia AGMA utiliza duas equações

tensões de deformação

$$\sigma = W_t K_o K_v K_s \frac{1}{b m_t} \frac{K_H K_B}{Y_j}$$

$$\sigma < \sigma_{total}$$

$$\sigma_{total} = \frac{S_t}{S_F} \frac{Y_N}{(K_T K_R)}$$

tensões de contato

$$\sigma_c = Z_E \sqrt{W_t K_o K_v K_s \frac{K_H}{d_{w1} b} \frac{Z_R}{Z_l}}$$

$$\sigma < \sigma_{c total}$$

$$\sigma_{c total} = \frac{S_c}{S_H} \frac{Z_N C_H}{(K_T K_R)}$$



Equação AGMA de tensão/deformação

- ▶ Na metodologia AGMA a equação de Lewis/Barth são corrigidas por uma série de fatores que procuram considerar todas as possíveis causas de falha de uma engrenagem.

$$\sigma = k_v K_A K_H \beta Y_X K_B \frac{W_t}{b m Y_J}$$

Carregamento transversal

Fator geométrico para *flexão*

módulo

Largura da face do dente

Fator de espessura

Fator de resistência a flexão

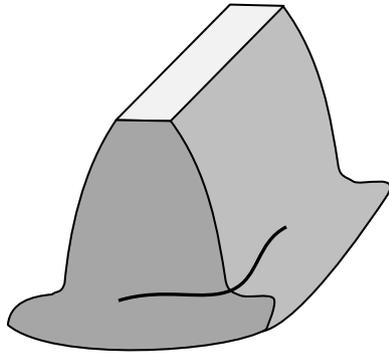
Fator de distribuição de carga

Fator de sobrecarga

Fator dinâmico



Critério de falha de tensão/deformação



$$\sigma < \sigma_{total}$$

Tensão AGMA de flexão

$$\sigma = k_v K_A K_H \beta Y_X K_B \frac{W_t}{b m Y_J}$$

Tensão de ciclos de fadiga a flexão

$$\sigma_{all} = \frac{\sigma}{S_F} \frac{Y_n}{Y_\theta Y_Z}$$

Fator de confiabilidade

Fator de temperatura

Fator de segurança a flexão



Equação AGMA de tensão de contato

- ▶ Na metodologia AGMA a equação de Lewis/Barth são corrigidas por uma série de fatores que procuram considerar todas as possíveis causas de falha de uma engrenagem.

$$\sigma_c = Z_E \sqrt{K_v K_A Y_X K_{H\beta} \left(\frac{W_t}{d_w b} \right) \left(\frac{Z_r}{Z_I} \right)}$$

Fator de superfície

Fator resistência para *pitting*

Espessura do dente

Diâmetro *pitch* do pinhão

Fator de distribuição de carga

Fator de resistência a flexão

Fator de sobrecarga

Fator dinâmico

Coeficiente elástico



Equação AGMA de tensão de contato

- ▶ Fator e coeficiente elástico - Z_E

$$\sigma_c = Z_E \sqrt{K_v K_A Y_X K_{H\beta} \left(\frac{W_t}{d_w b}\right) \left(\frac{Z_r}{Z_I}\right)}$$

→ Fator de Coeficiente elástico

$$Z_E = \left[\frac{1}{\pi \left(\frac{1 - \nu_p^2}{E_p} + \frac{1 - \nu_G^2}{E_G} \right)} \right]$$



Equação AGMA de tensão de contato

$$\sigma < \sigma_{c_{total}}$$

Tensão AGMA de contato

$$\sigma_c = Z_E \sqrt{K_v K_A Y_X K_{H\beta} \left(\frac{W_t}{d_w b} \right) \left(\frac{Z_r}{Z_I} \right)}$$

$$\sigma_{c_{all}} = \frac{\sigma_c Z_n Z_w}{S_H Y_\theta Y_Z}$$

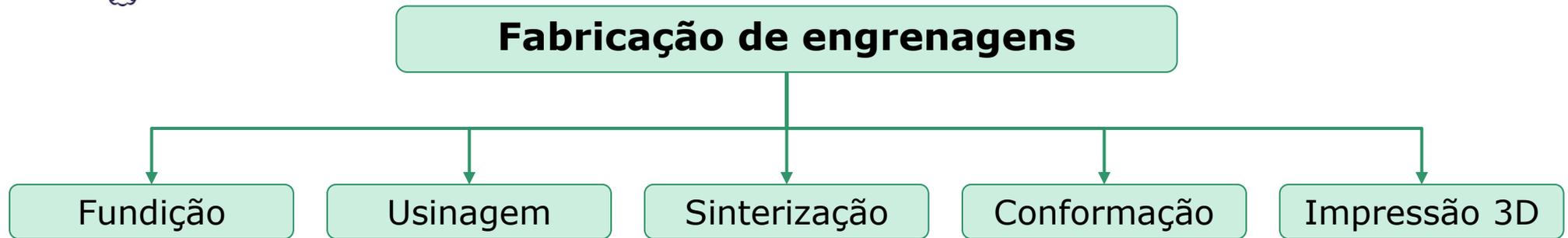
Fator de ciclo fadiga

Razão de dureza para resistência
ao pitting

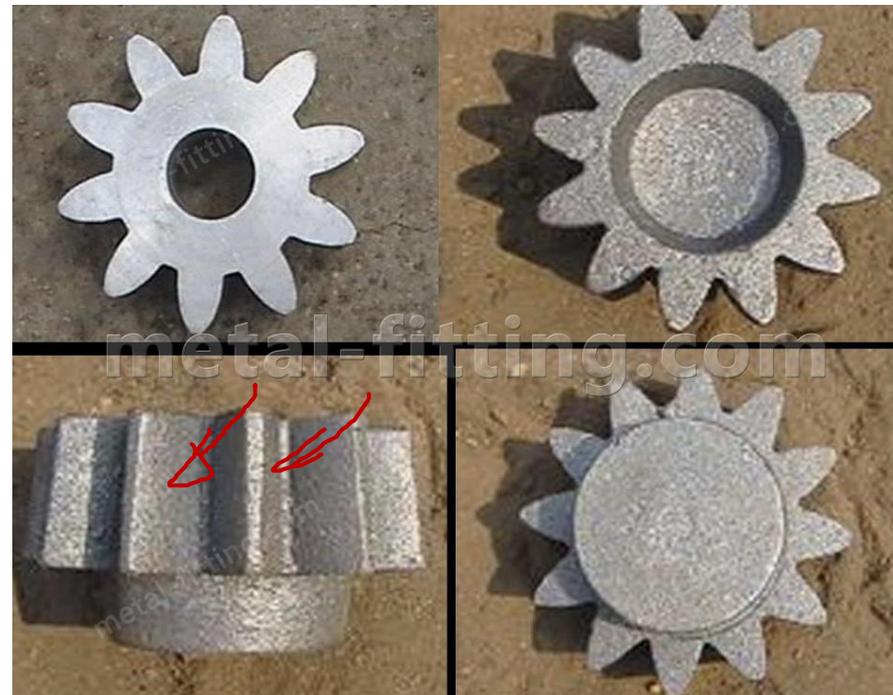
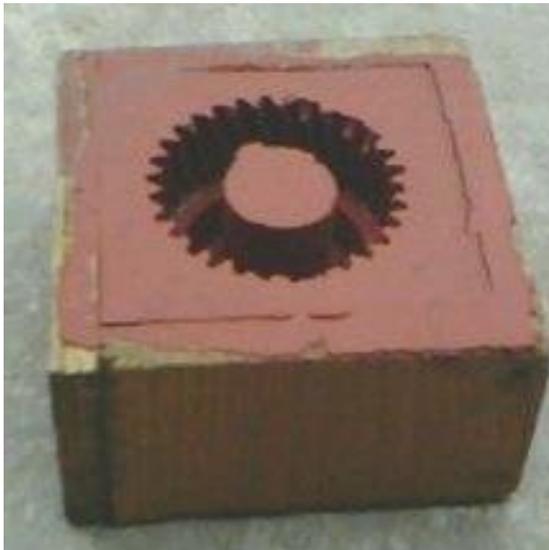
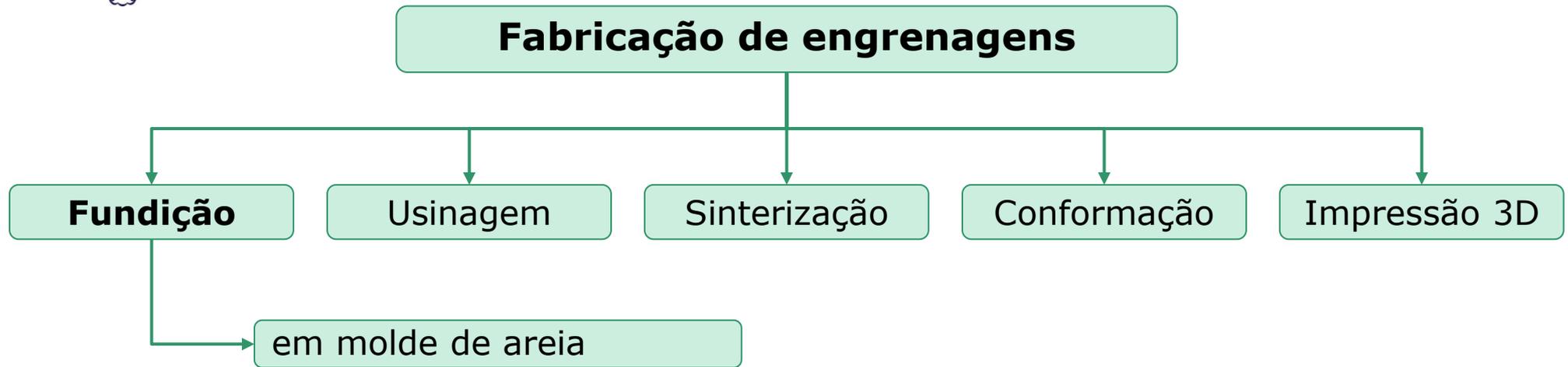
Fator de confiabilidade

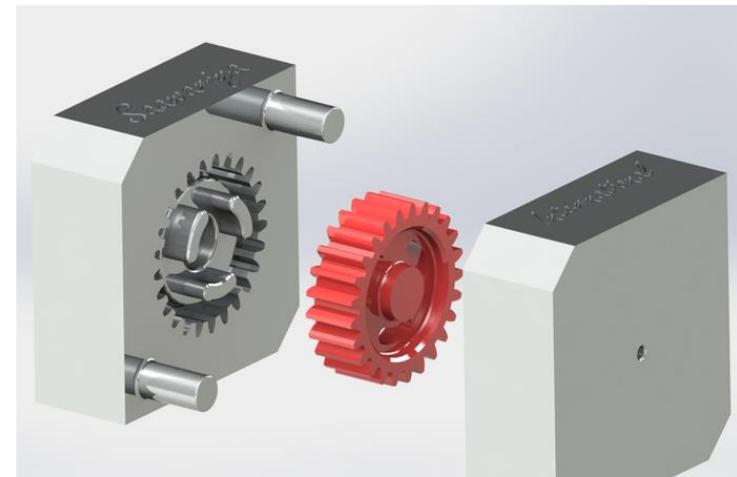
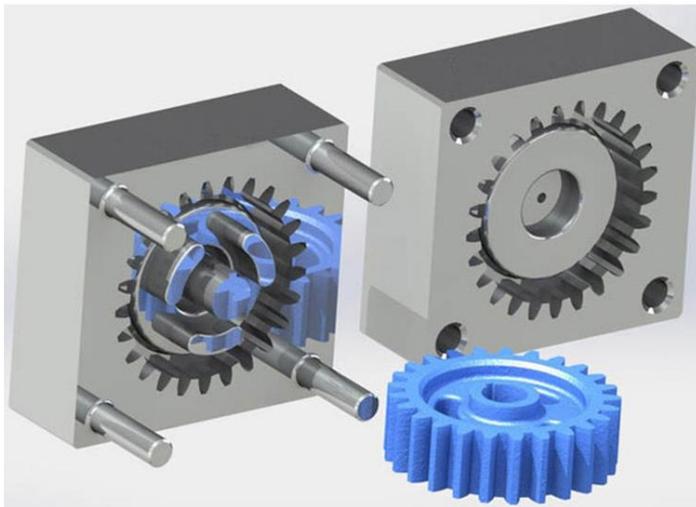
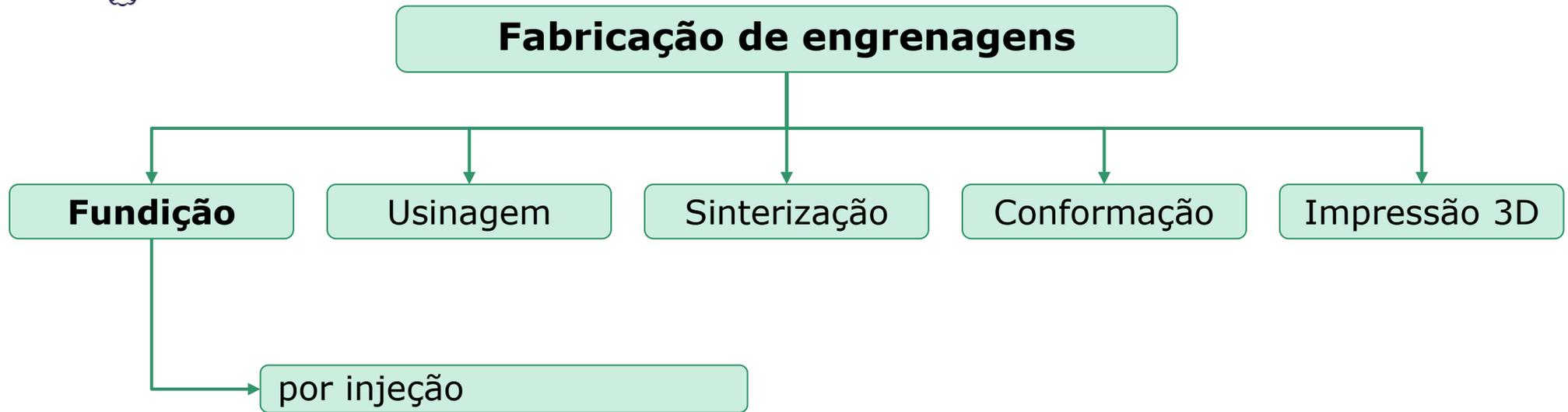
Fator de temperatura

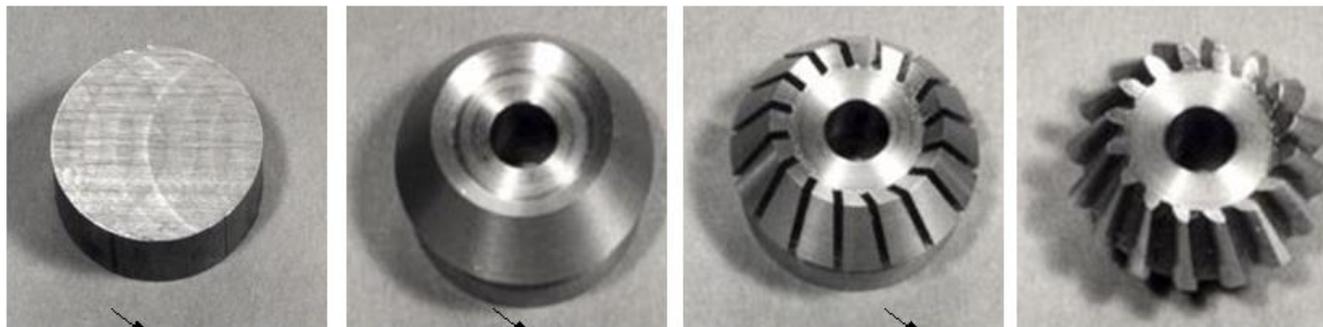
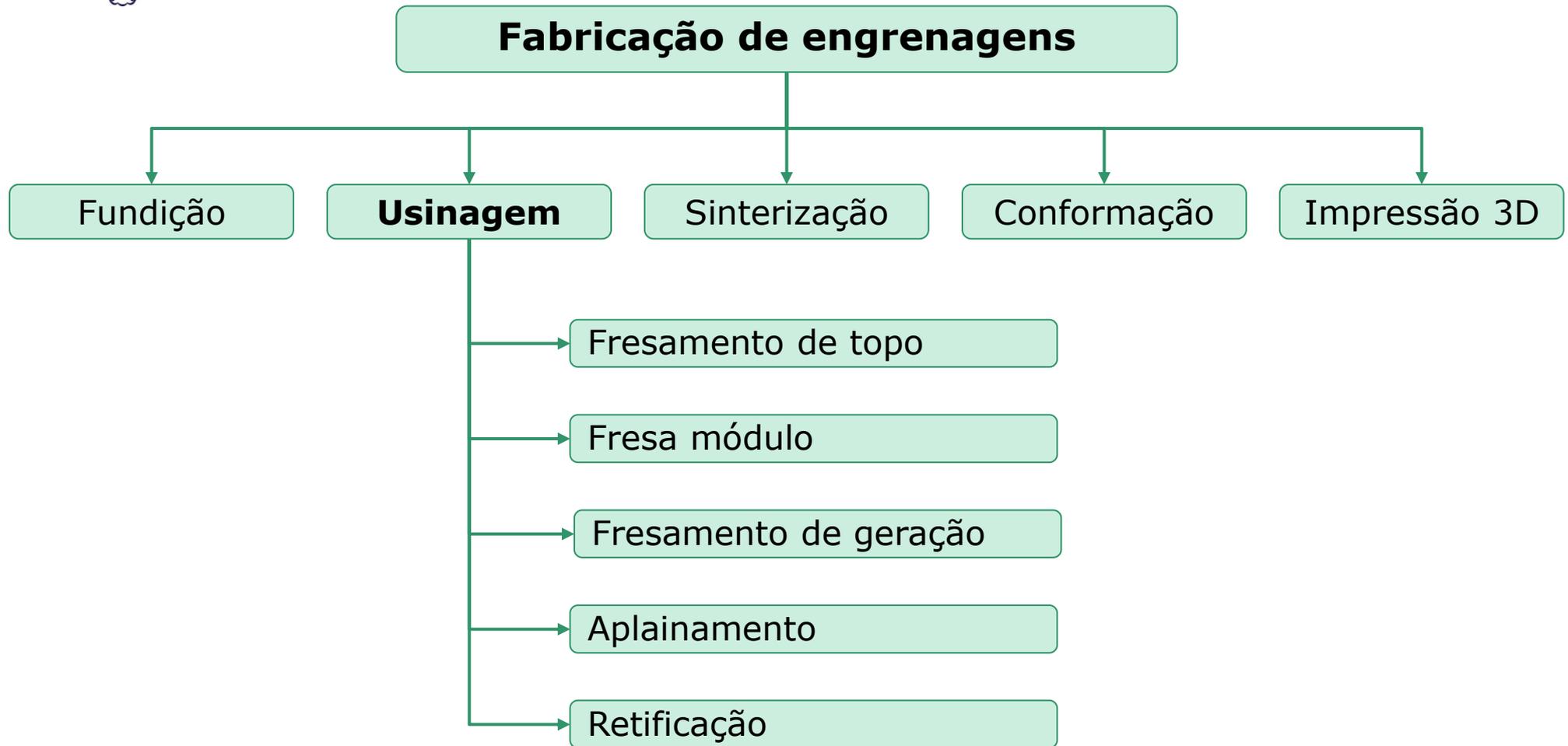
Fator de segurança

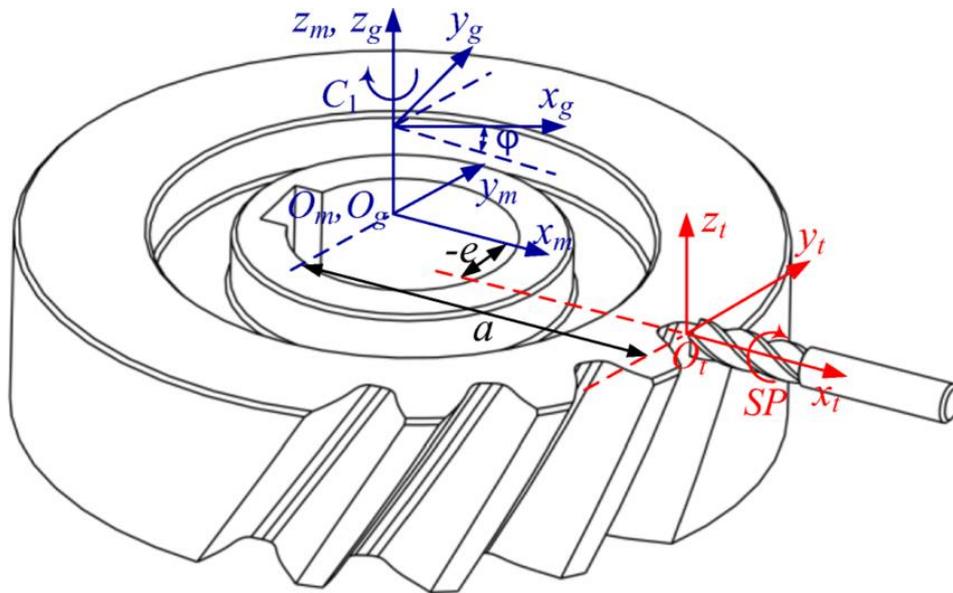
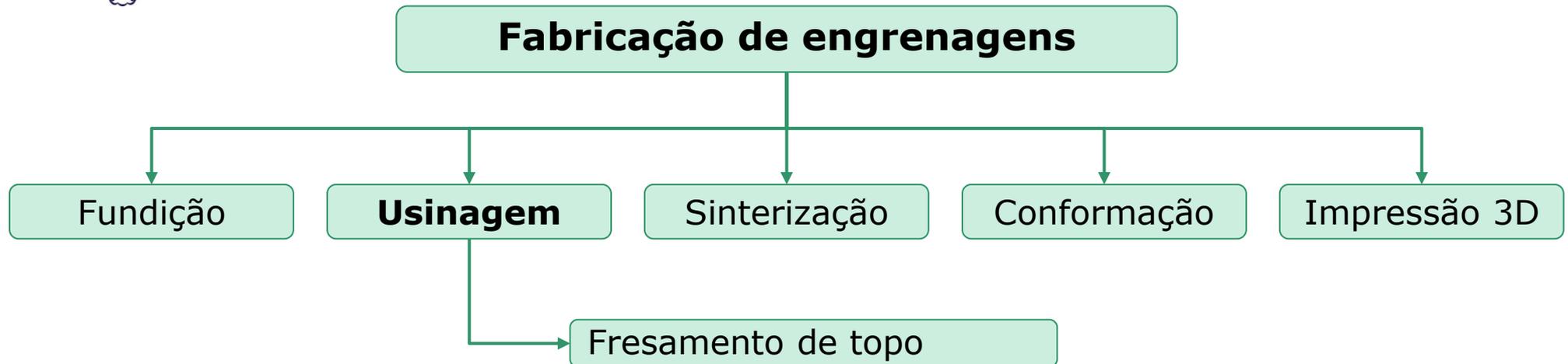


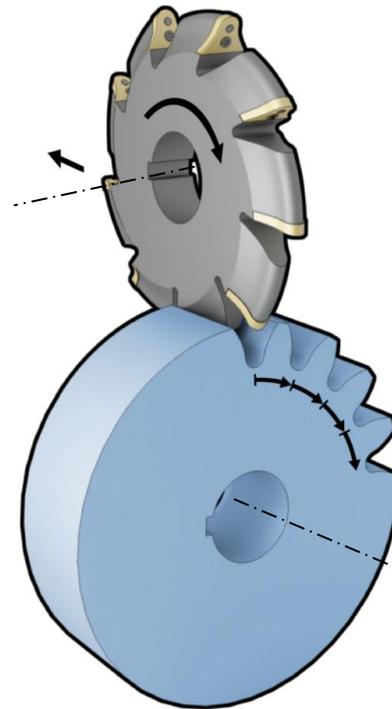
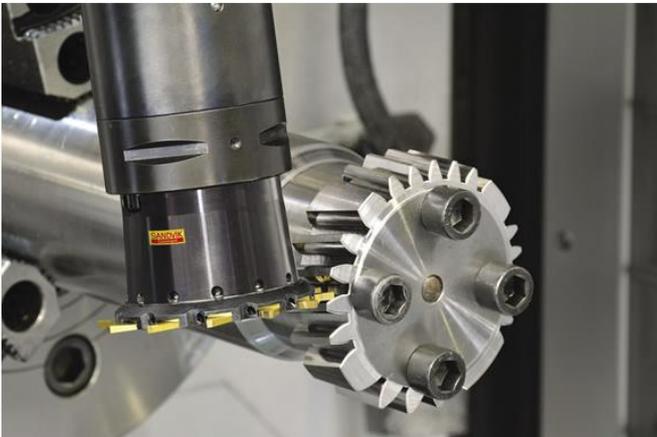
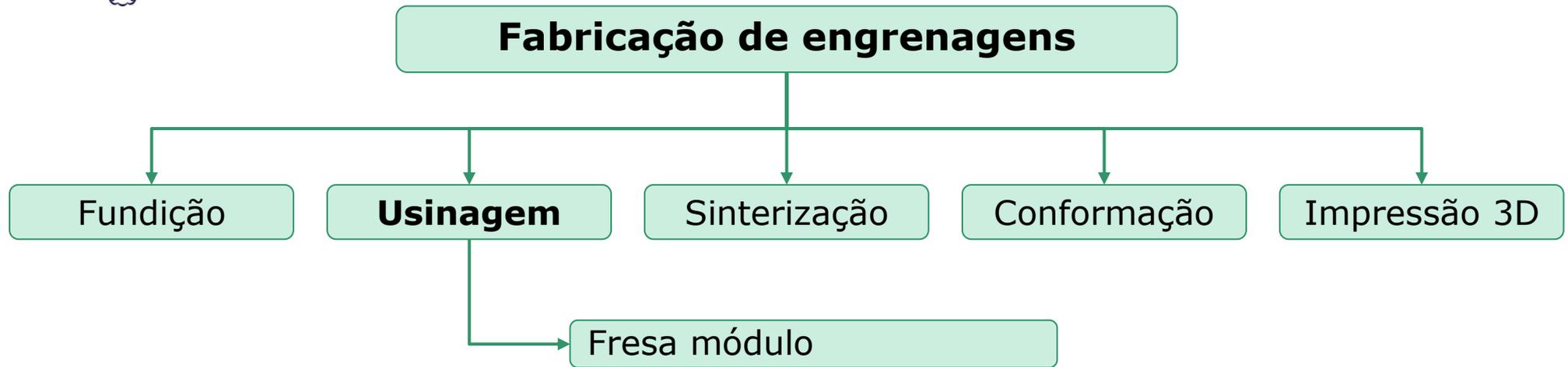


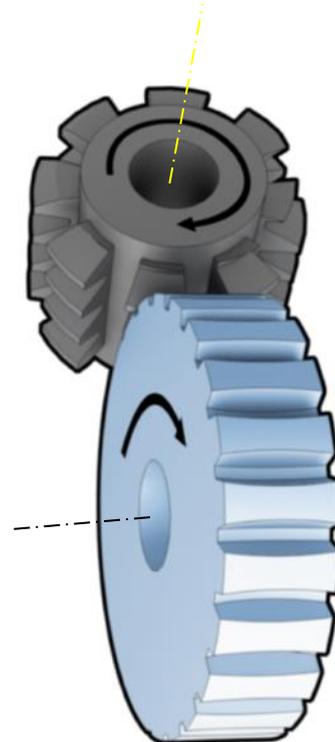
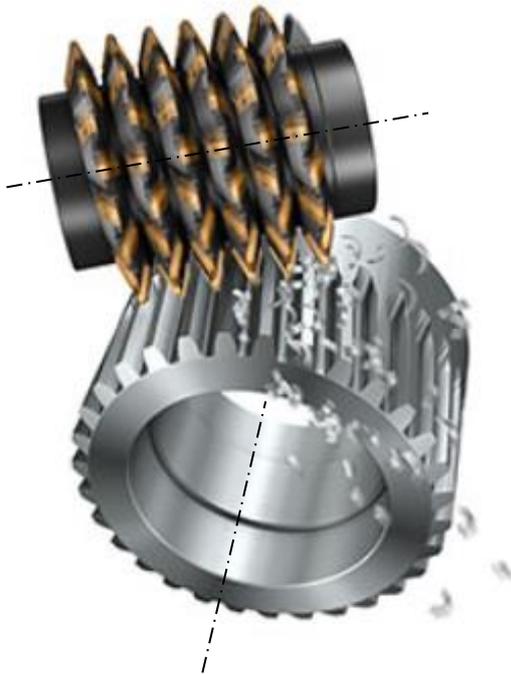
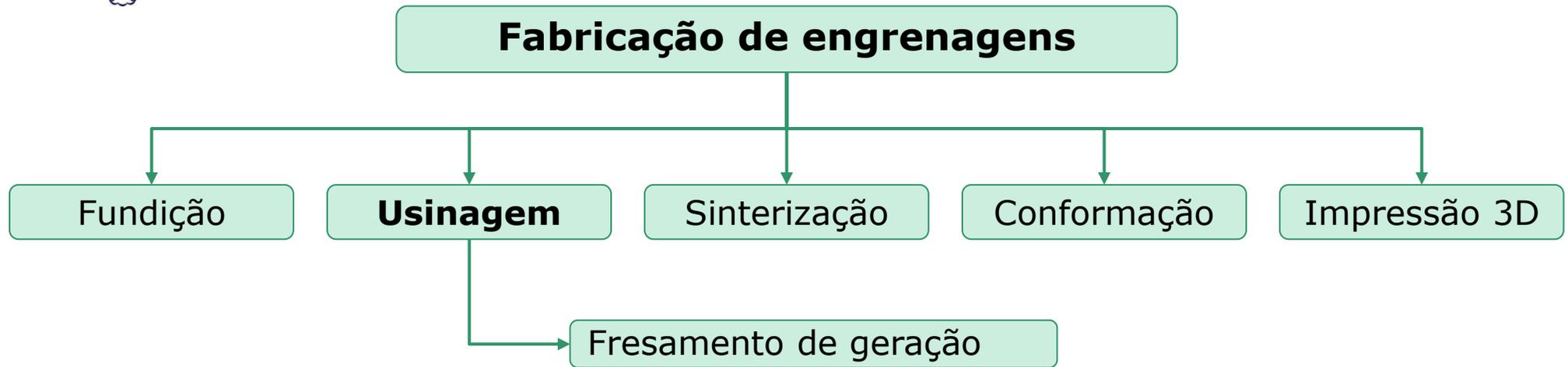


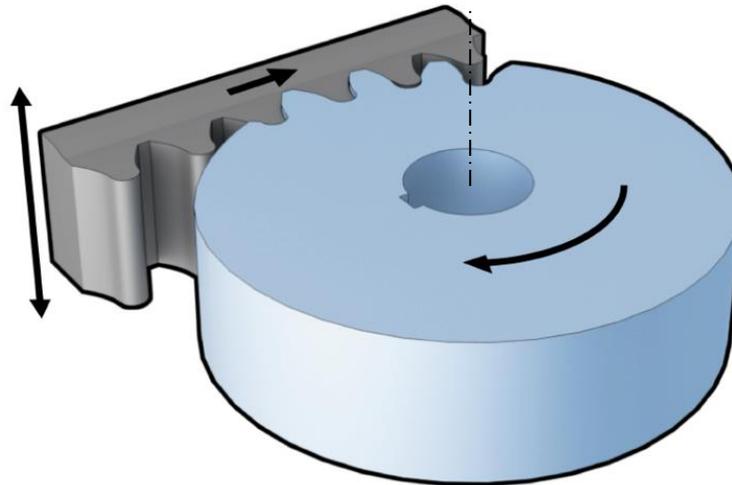
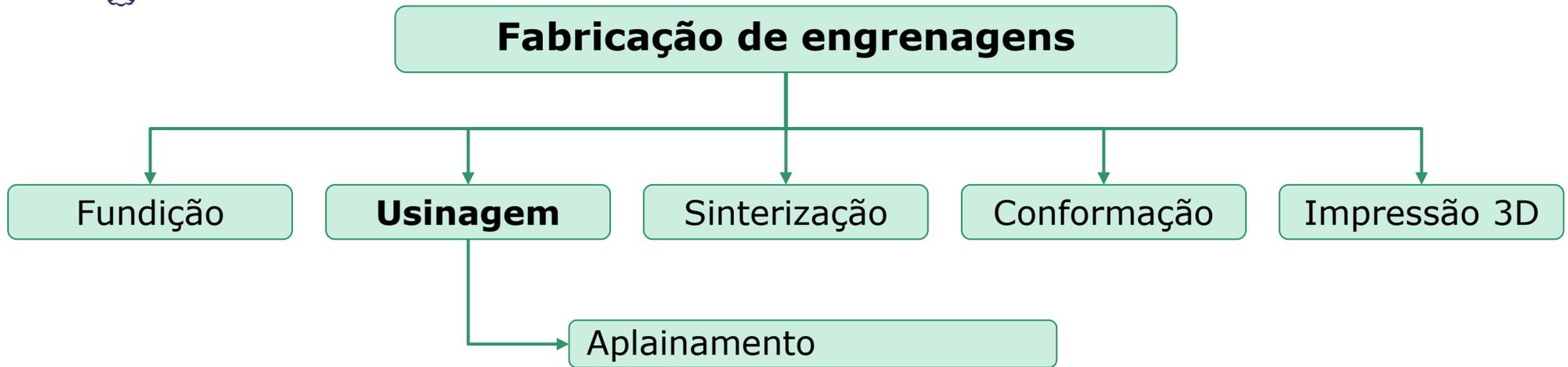


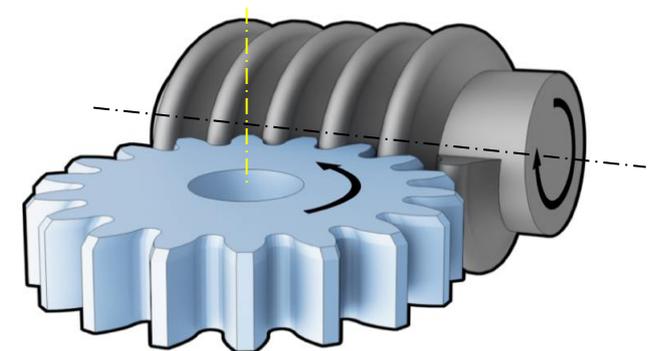
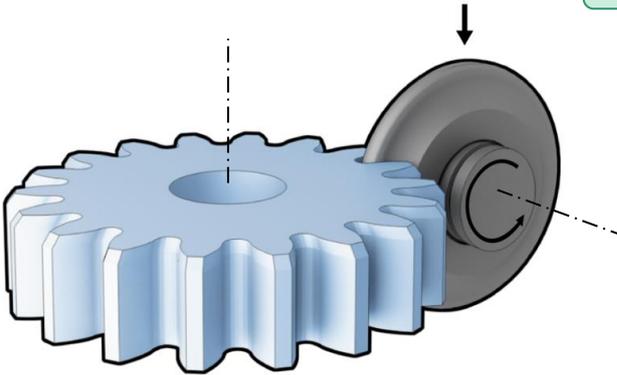
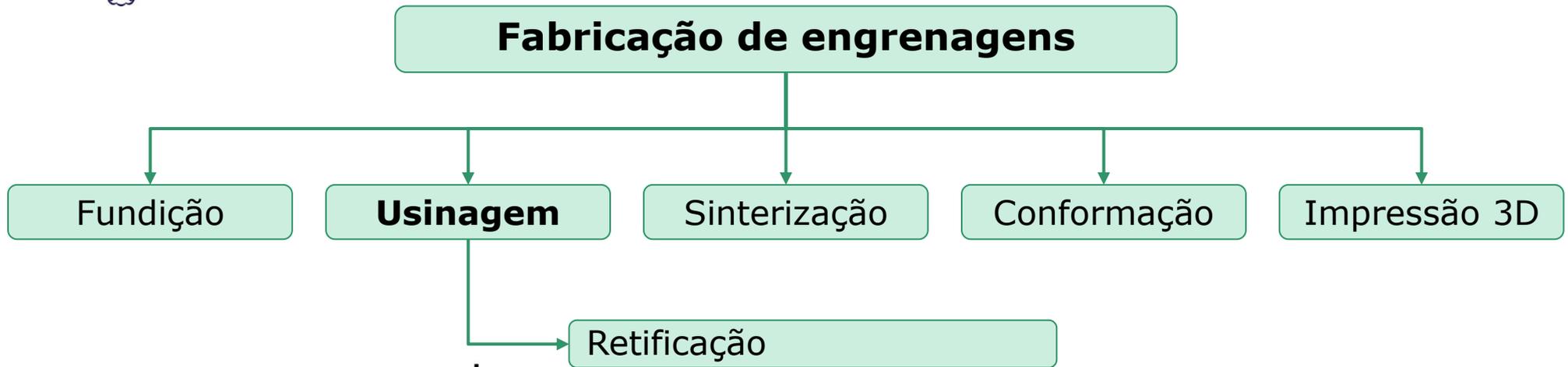


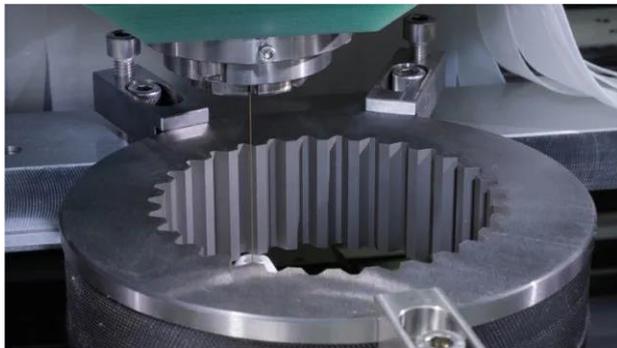
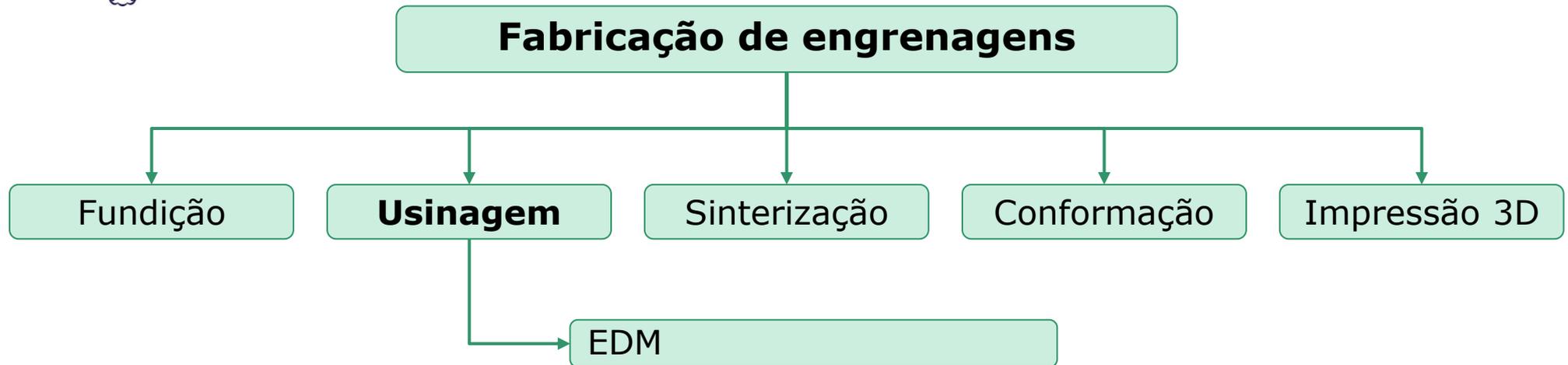


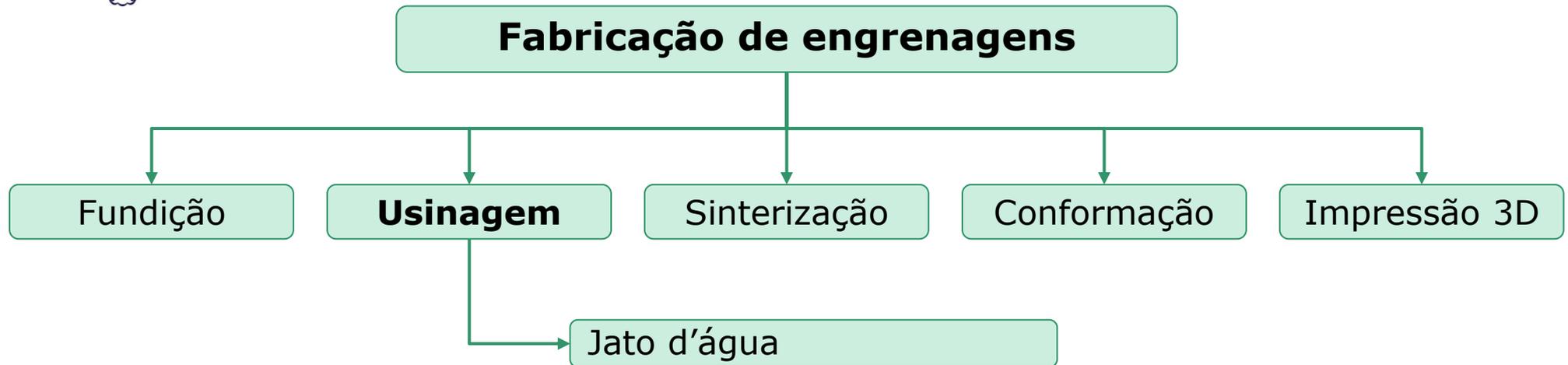


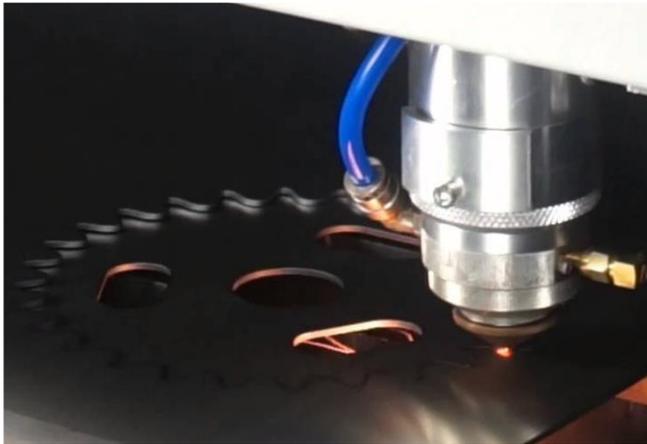
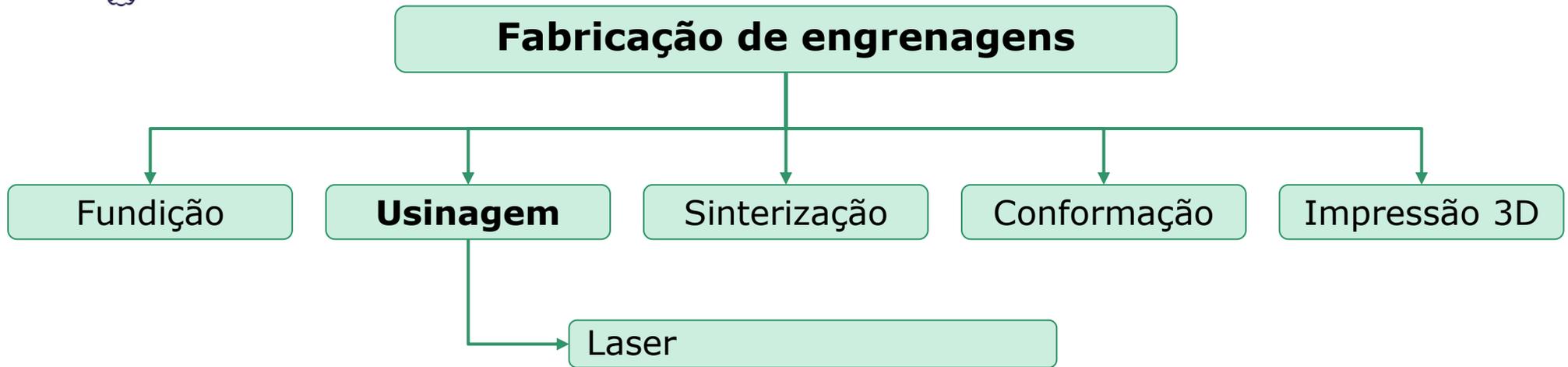














Fabricação de engrenagens

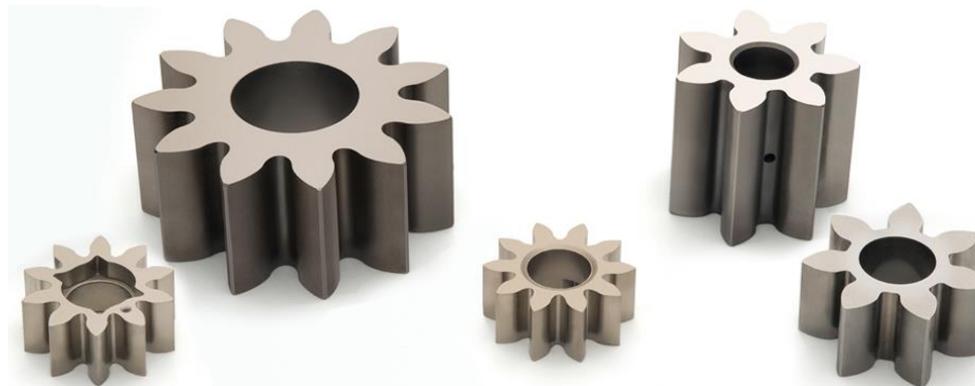
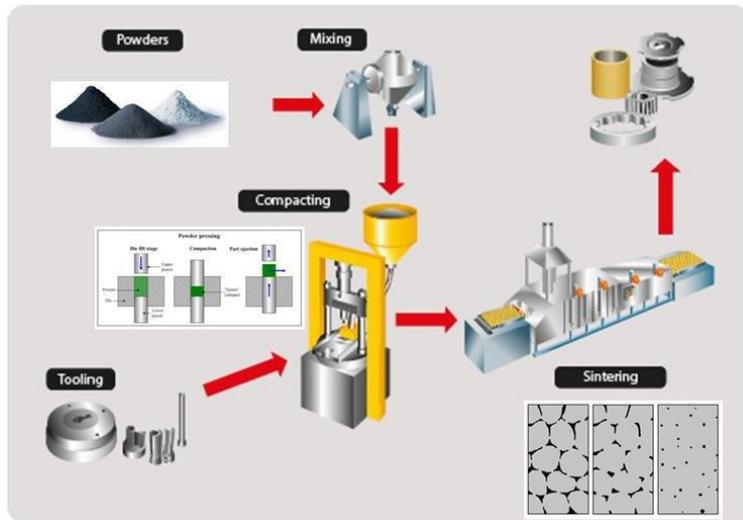
Fundição

Usinagem

Sinterização

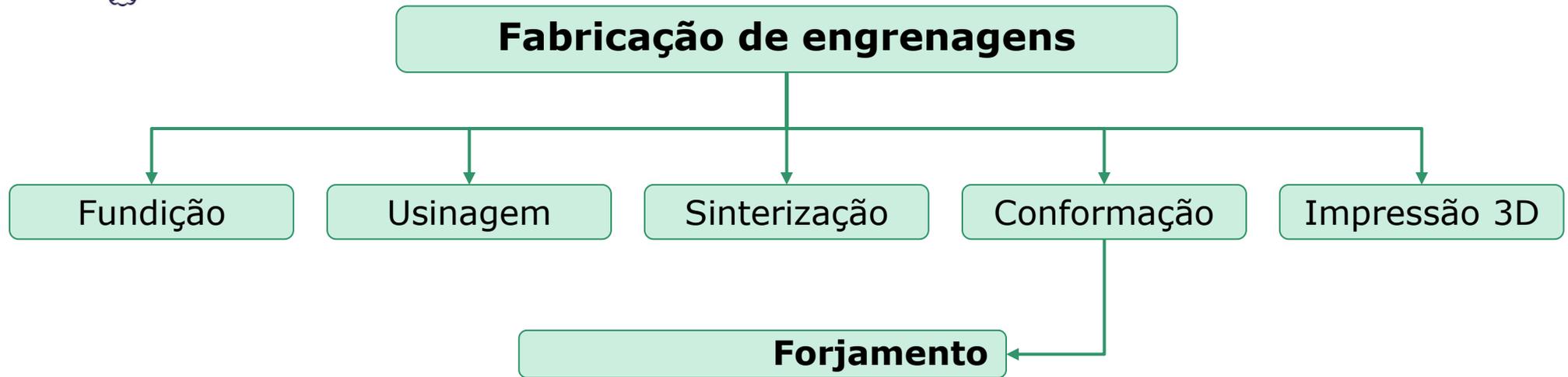
Conformação

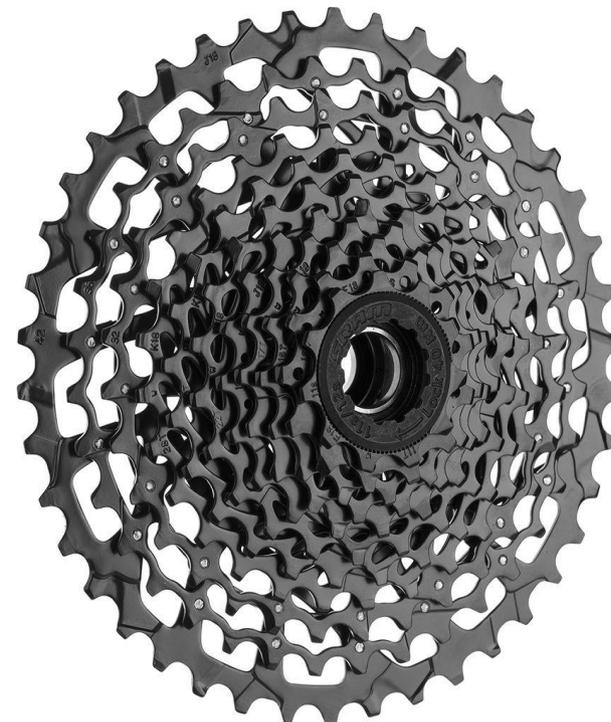
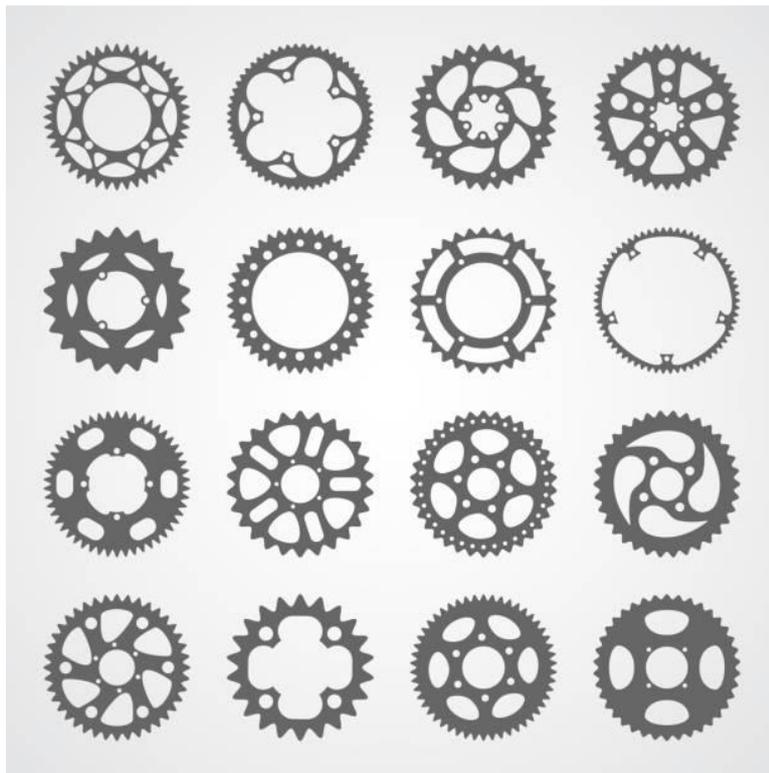
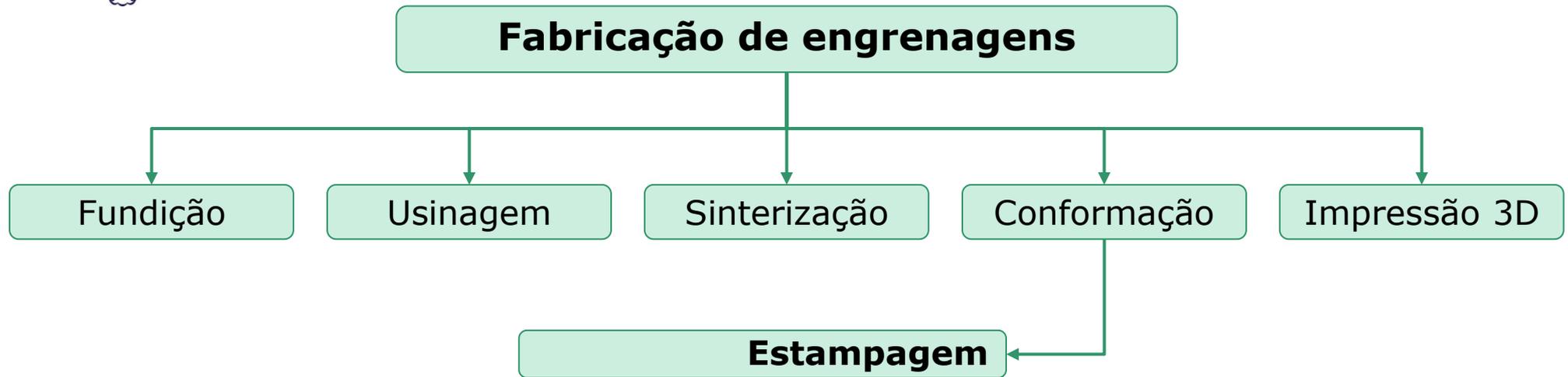
Impressão 3D

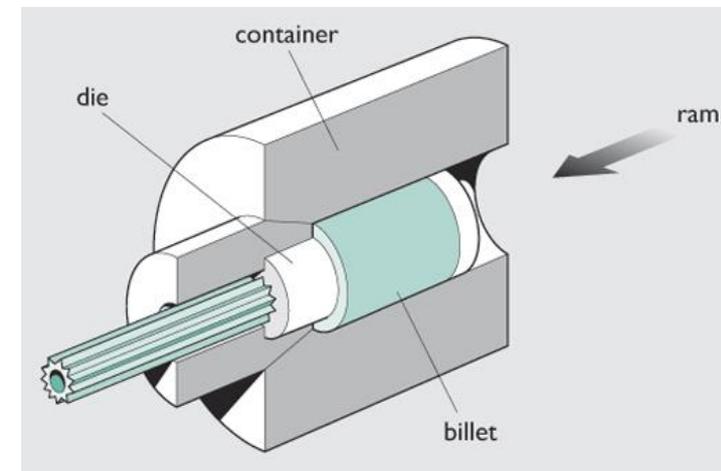
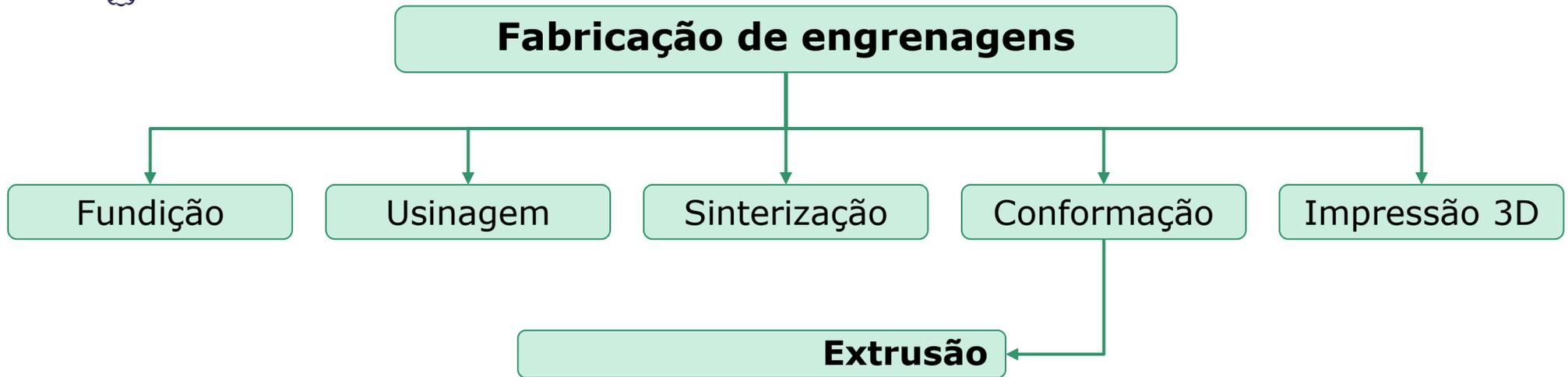


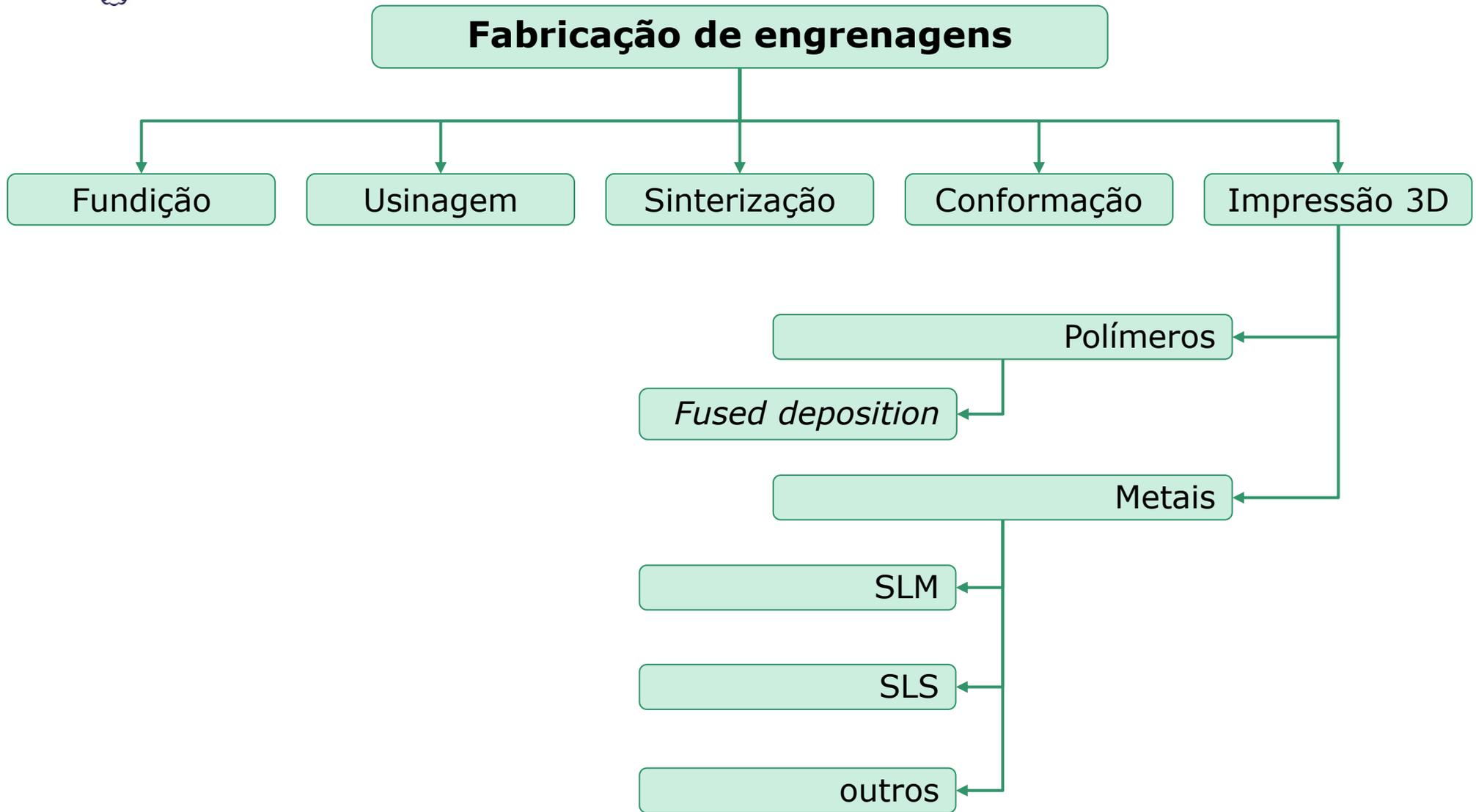


<https://www.youtube.com/watch?v=oDWEcpNLfdI>











Fabricação de engrenagens

Fundição

Usinagem

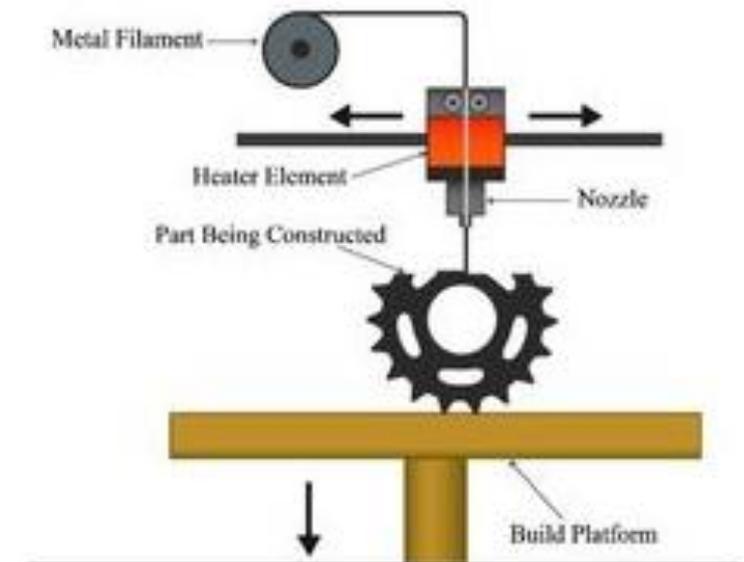
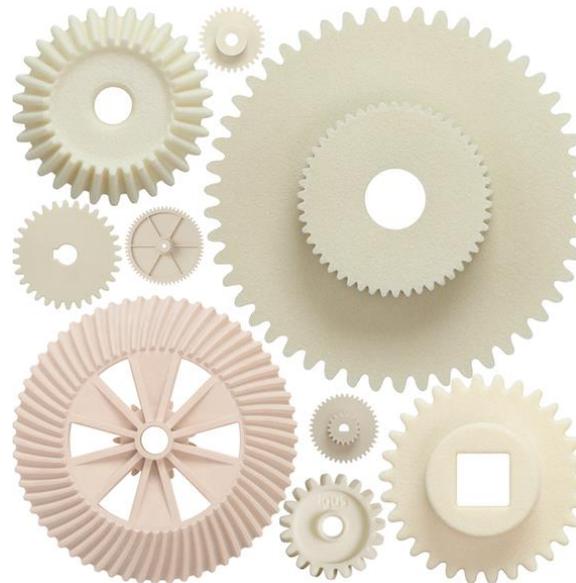
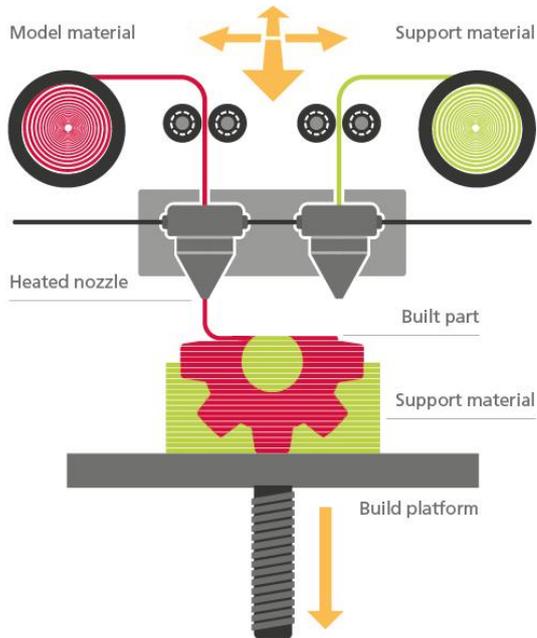
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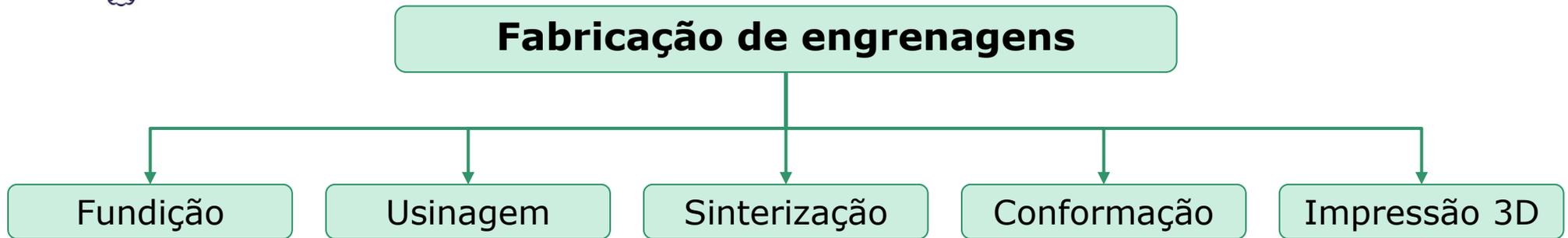
Conformação

Impressão 3D

Polímeros

Fused deposition



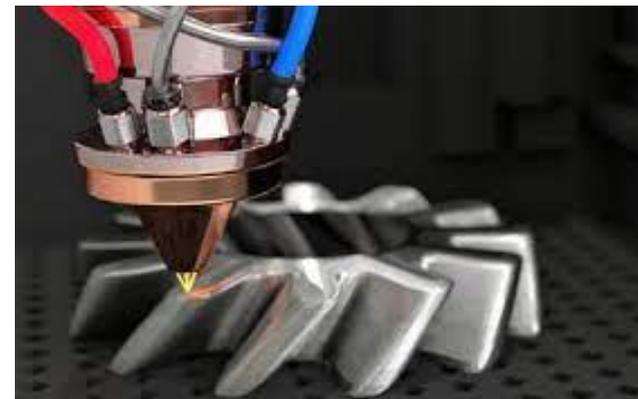
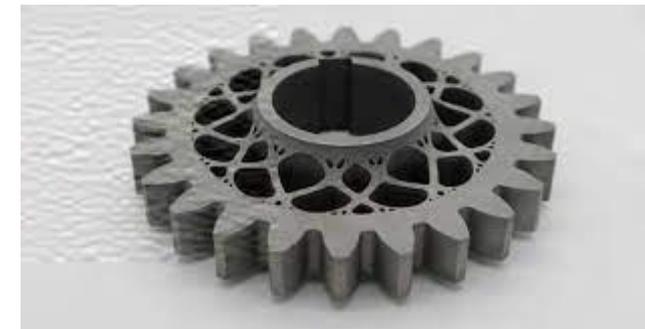


Metals

SLM

SLS

outros





FIM DA AULA