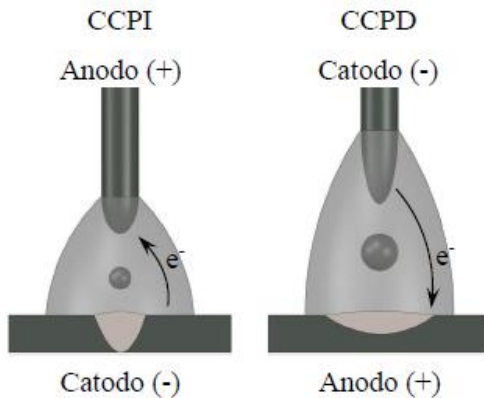


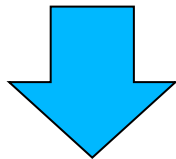
Il laser come strumento versatile nella saldatura: lo stato dell'arte, la ricerca e le nuove tendenze

prof. Alessandro Ascari

ARCO ELETTRICO

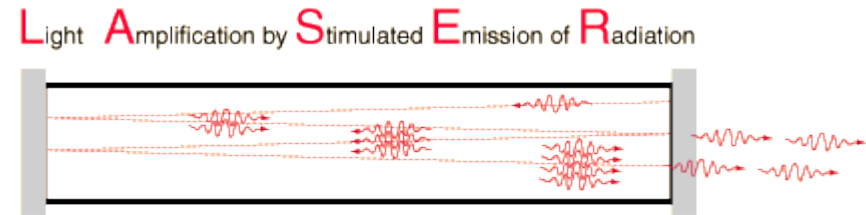


Flusso di elettroni

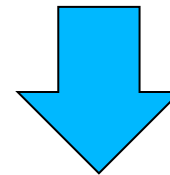


Corrente elettrica

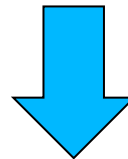
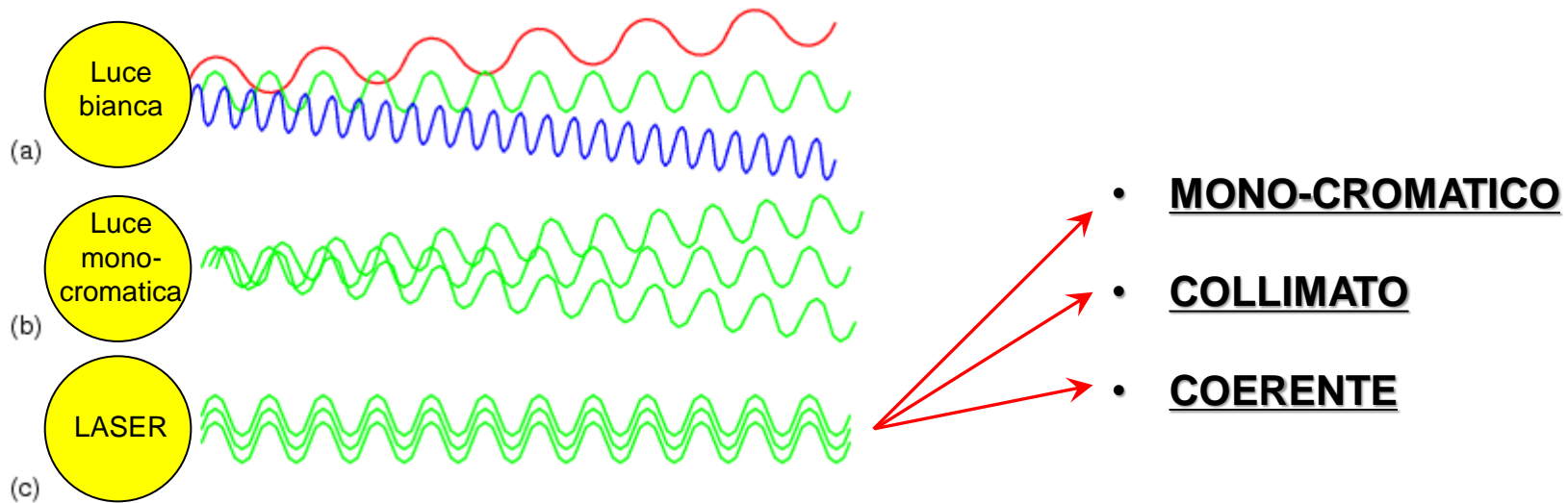
LASER



Flusso di fotoni

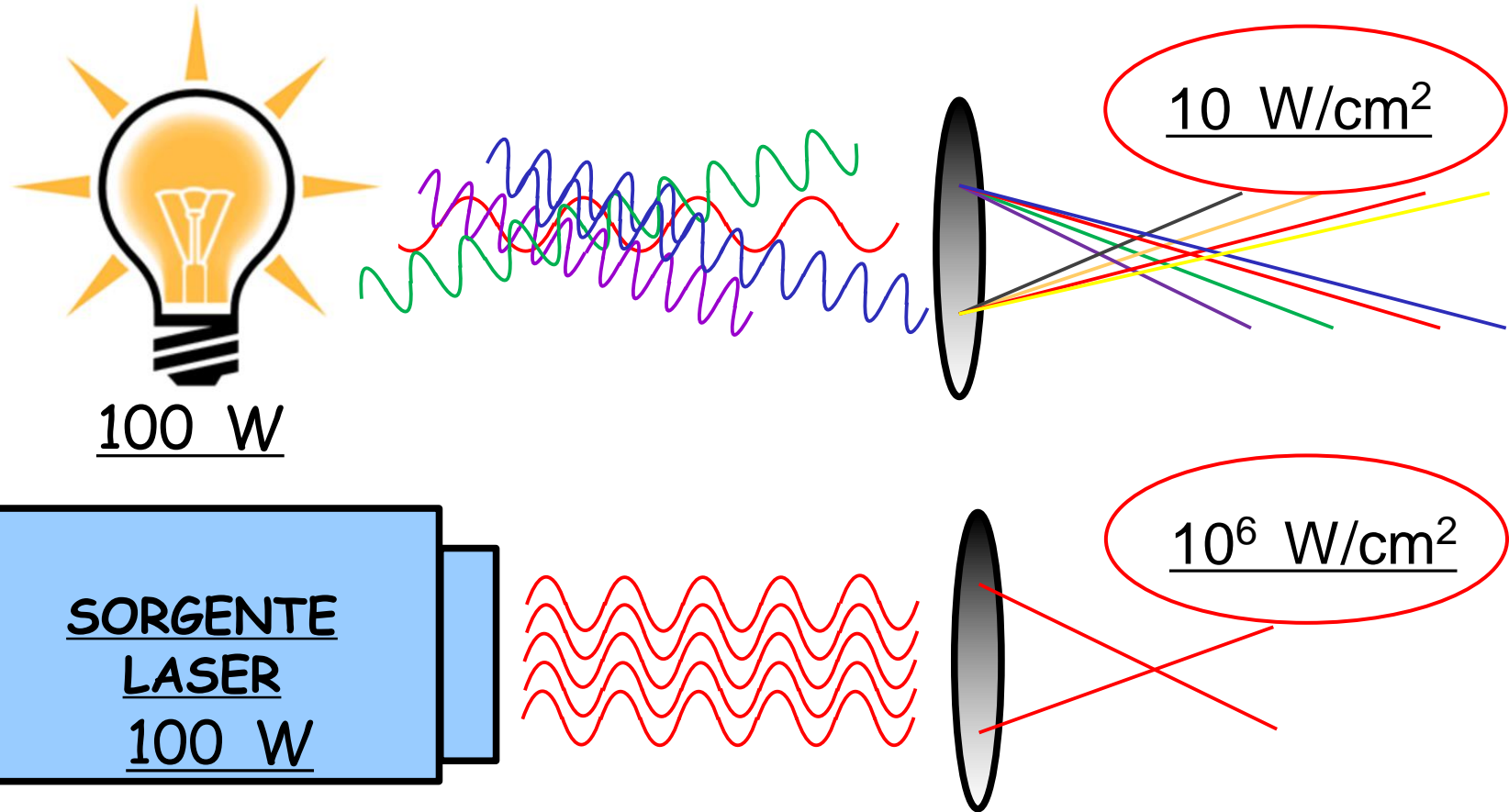


Lavoriamo con la luce !



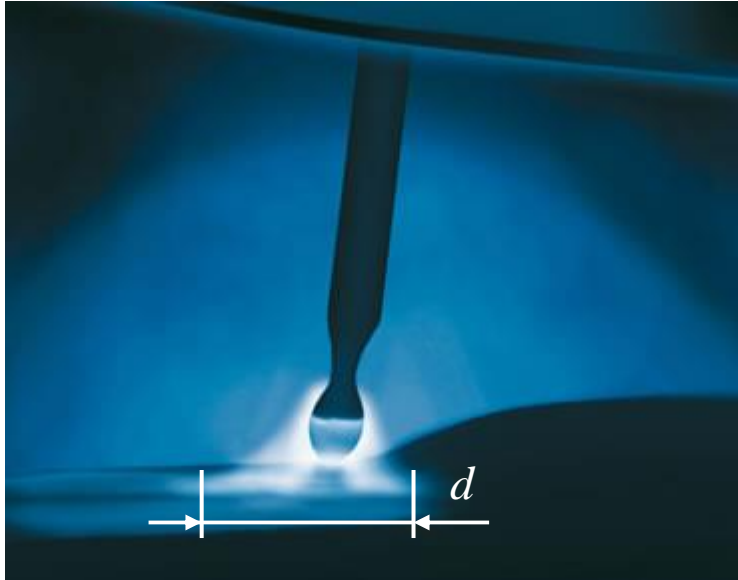
Facilmente focalizzabile

Focalizzare il fascio LASER



A parità di potenza ottengo maggiore densità di potenza

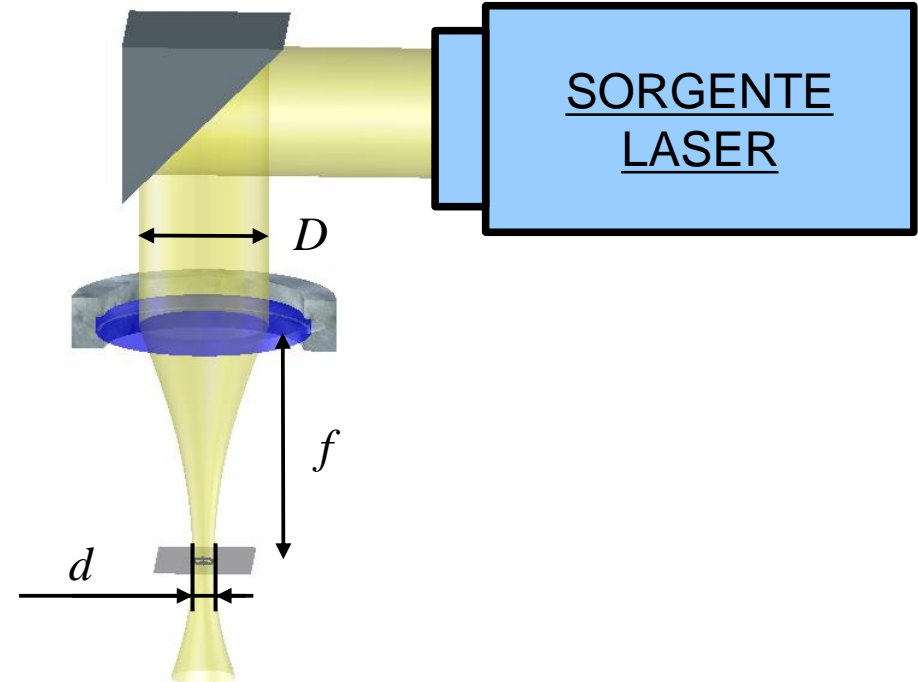
Manipolare la luce



$$P = 10 \text{ kW}$$

$$d = 5 \text{ mm}$$

$$P_{dens} = 51 \frac{\text{kW}}{\text{cm}^2}$$

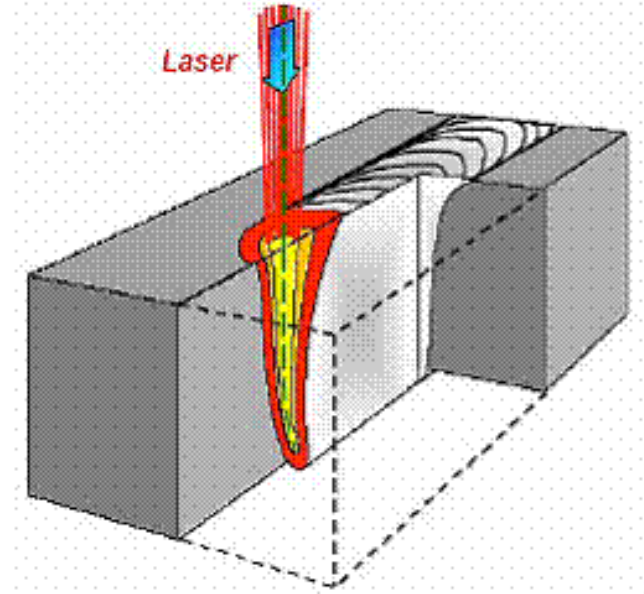
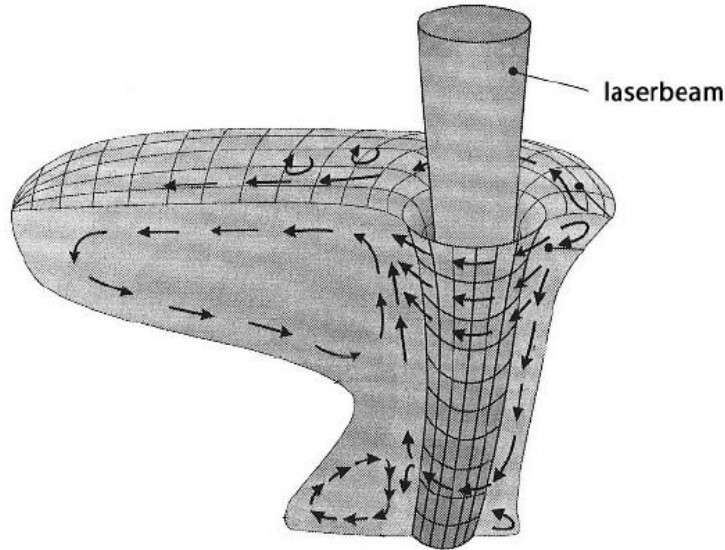


$$P = 10 \text{ kW}$$

$$d = 0.15 \text{ mm}$$

$$P_{dens} = 56600 \frac{\text{kW}}{\text{cm}^2}$$

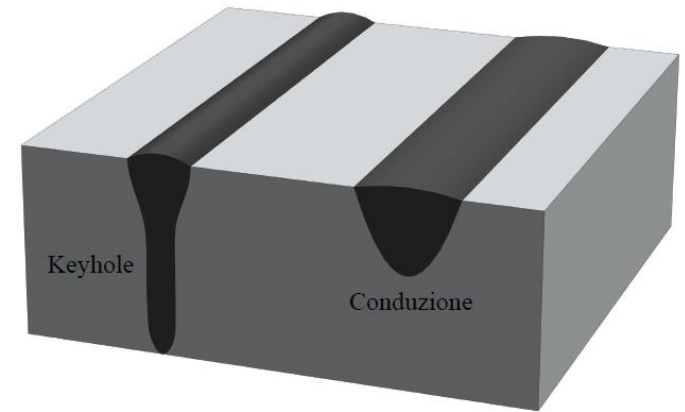
Saldatura laser: il keyhole



L'altissima densità di potenza provoca la vaporizzazione del metallo fuso, favorendo l'apertura di un «foro» all'interno del quale il fascio penetra, riscaldando non più solo la superficie del pezzo ma, in profondità, tutta la parete del foro stesso.

Vantaggi del keyhole - 1

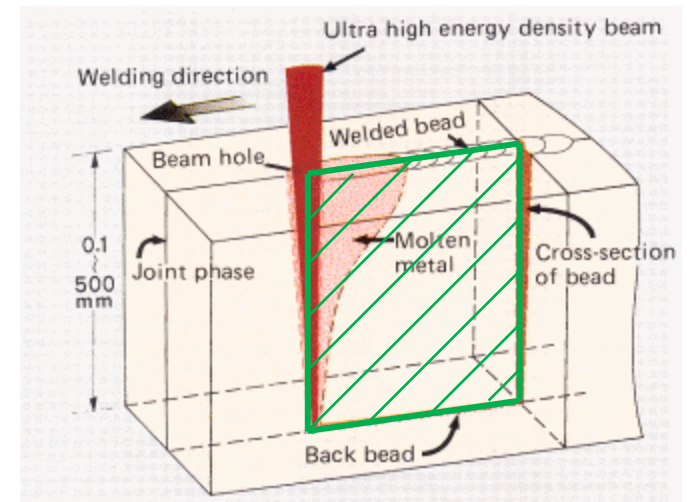
Elevata penetrazione e cordoni molto snelli



Rendimento di giunzione elevato

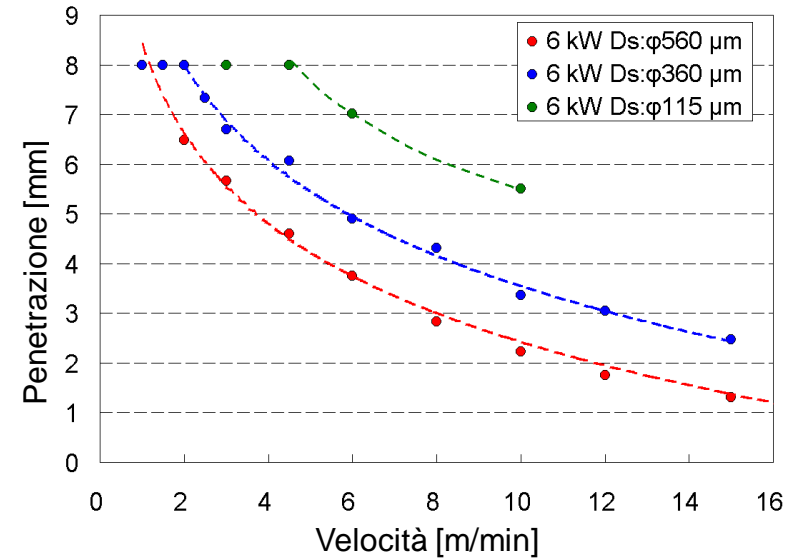
$$\eta_{laser} = \frac{vP_{en}}{P_{ot}} = 15 \div 30 \frac{mm^2}{kJ}$$

$$\eta_{arco} = \frac{vP_{en}}{P_{ot}} = 2 \div 5 \frac{mm^2}{kJ}$$



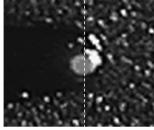
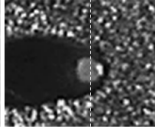
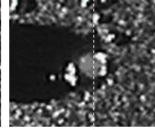
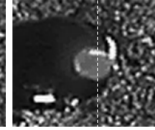
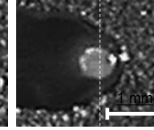
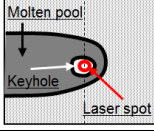
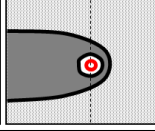
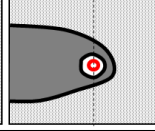
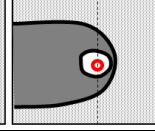
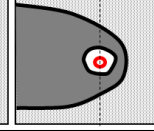
Vantaggi del keyhole - 2

Elevata velocità di saldatura



Welding speed: 3 m/min, Laser spot diameter: 200 µm, Shielding gas: Argon 40 l/min

Elevato assorbimento della radiazione

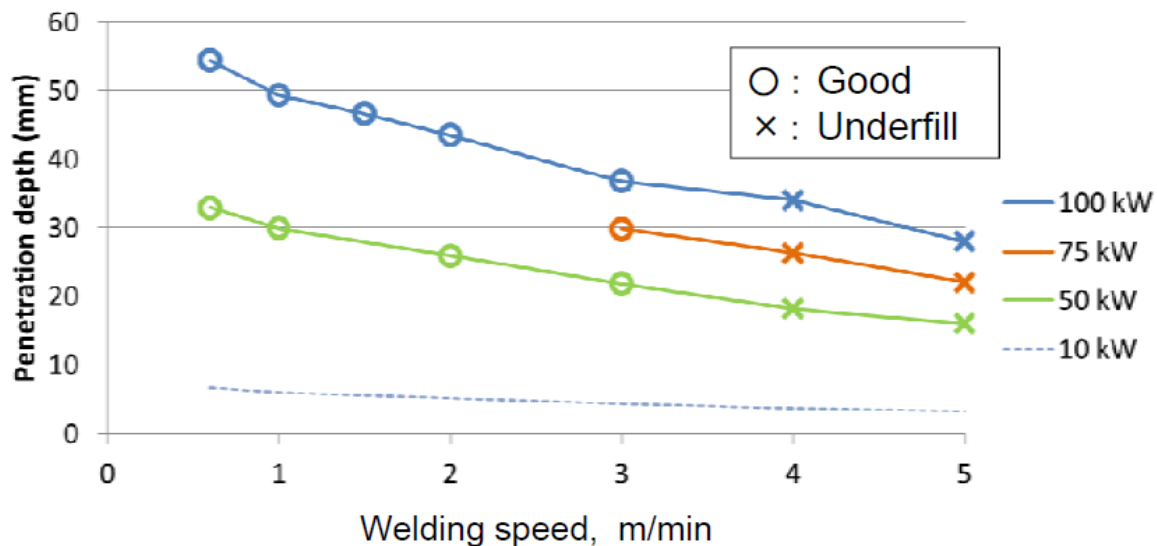
Laser power	2 kW	4 kW	6 kW	8 kW	10 kW
High speed images					
Schematic illustration					
Keyhole diameter	0.42 mm	0.48 mm	0.54 mm	0.58 mm	0.62 mm
Absorption	75 %	83 %	82 %	82 %	84 %

Laser in saldatura: dove siamo arrivati ?

- **Saldatura autogena senza materiale d'apporto**
- **Saldatura autogena con materiale d'apporto**
- **Saldatura ibrida (LASER+arco)**
- **Saldatura in regime impulsato per piccoli spessori**
- **Brasatura**

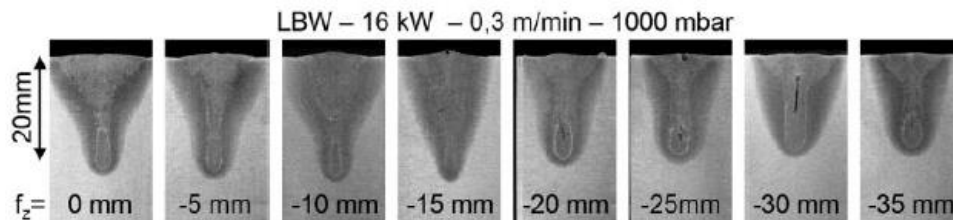
La massima potenza di una sorgente LASER commerciale attualmente è di oltre 100 kW !

- **Penetrazioni fino a 40 mm a 3 m/min e fino a 55 mm a 0.6 m/min**
- **Penetrazioni oltre 130 mm in vuoto**

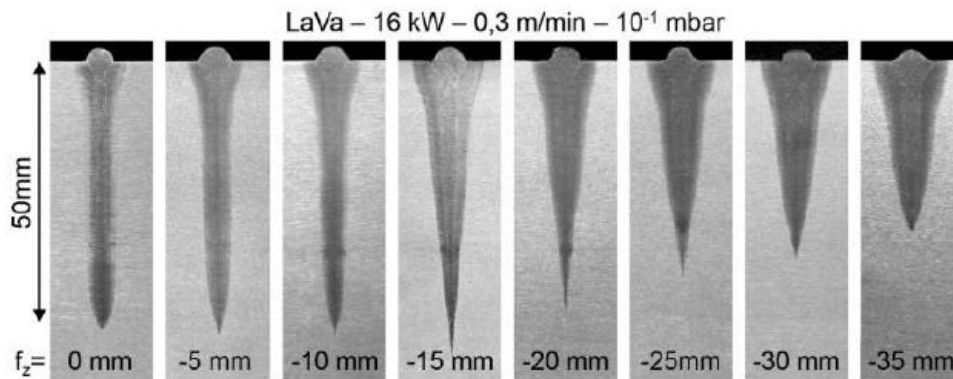


Katayama et al.

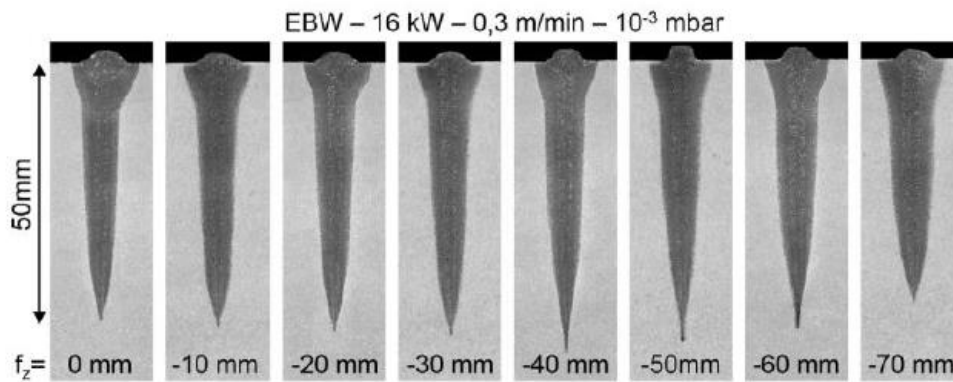




LASER a pressione ambiente

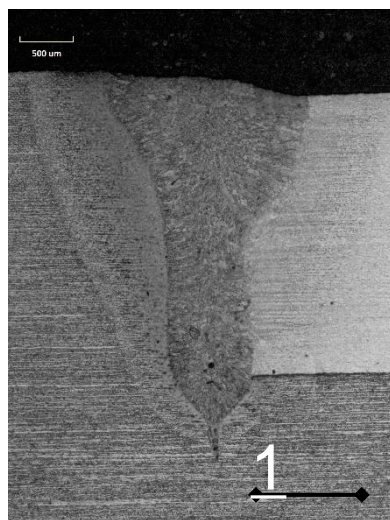
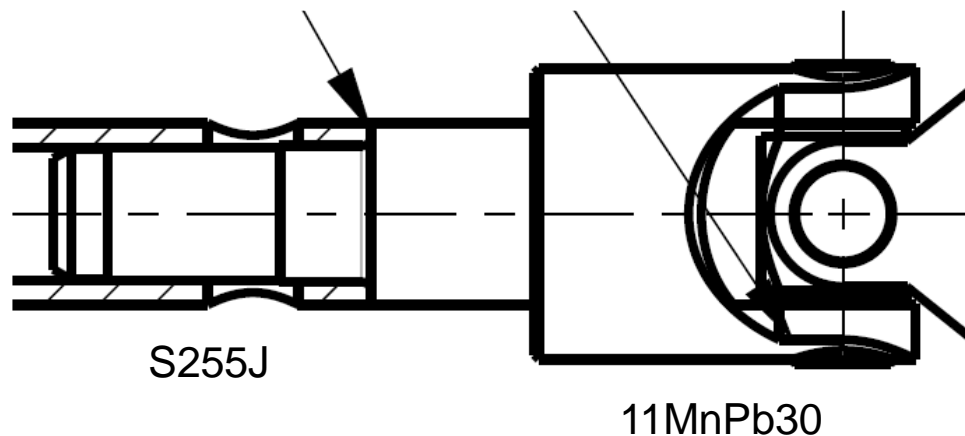


LASER in vuoto



Fascio elettronico in vuoto

Reisgen et al.



Parametri di prova:

Potenza = 1.5 kW

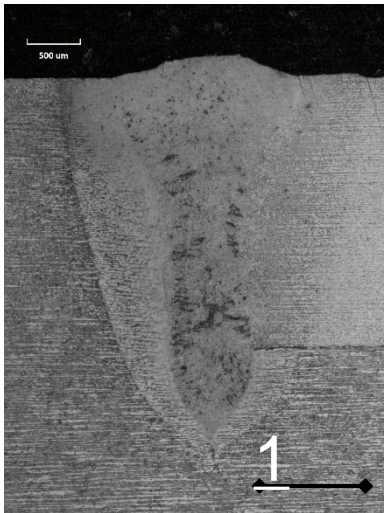
Velocità = 1.0 m/min

Esempi di saldature



11MnPb30

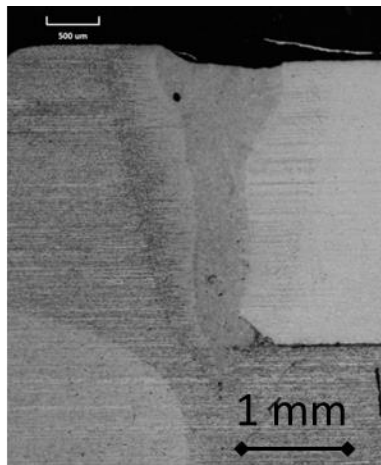
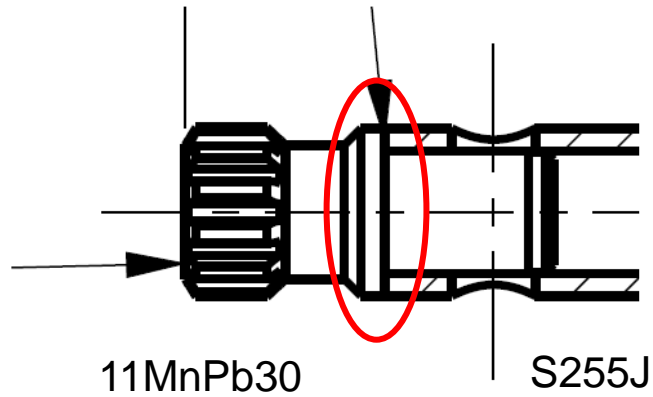
S255J



Parametri di prova:

Potenza = 1.5 kW

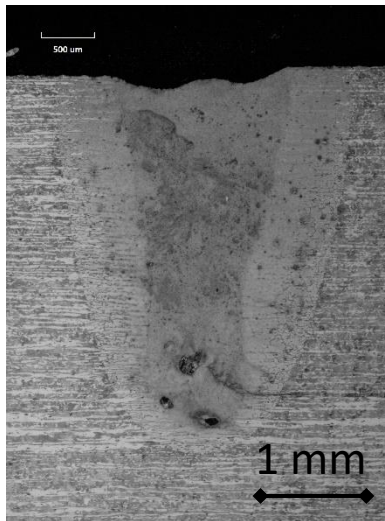
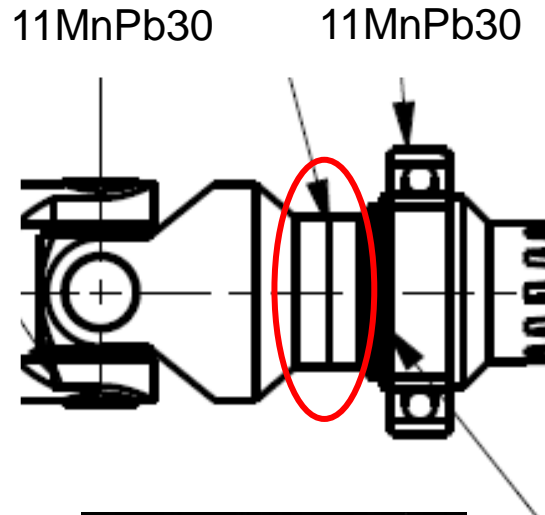
Velocità = 1.0 m/min



Parametri di prova:

Potenza = 1.5 kW

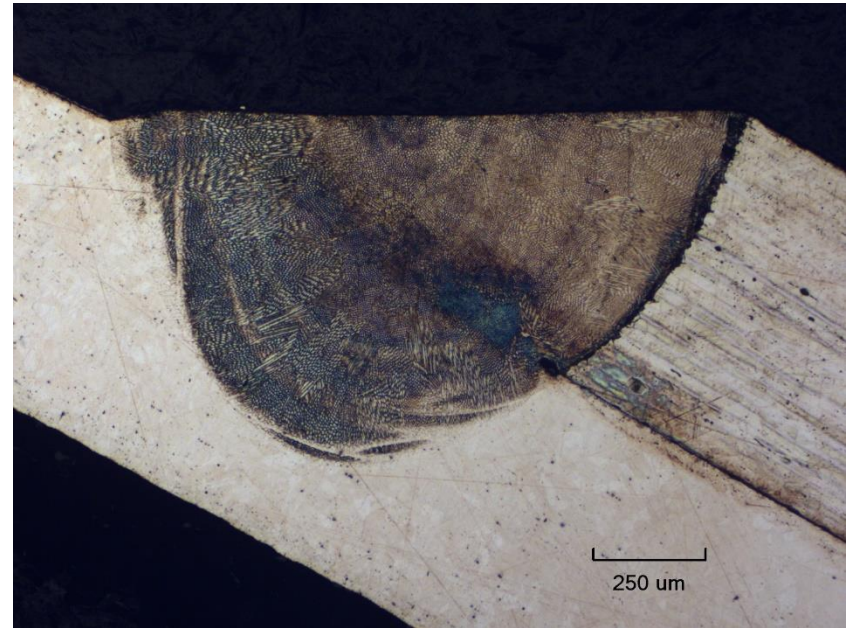
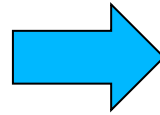
Velocità = 1.0 m/min



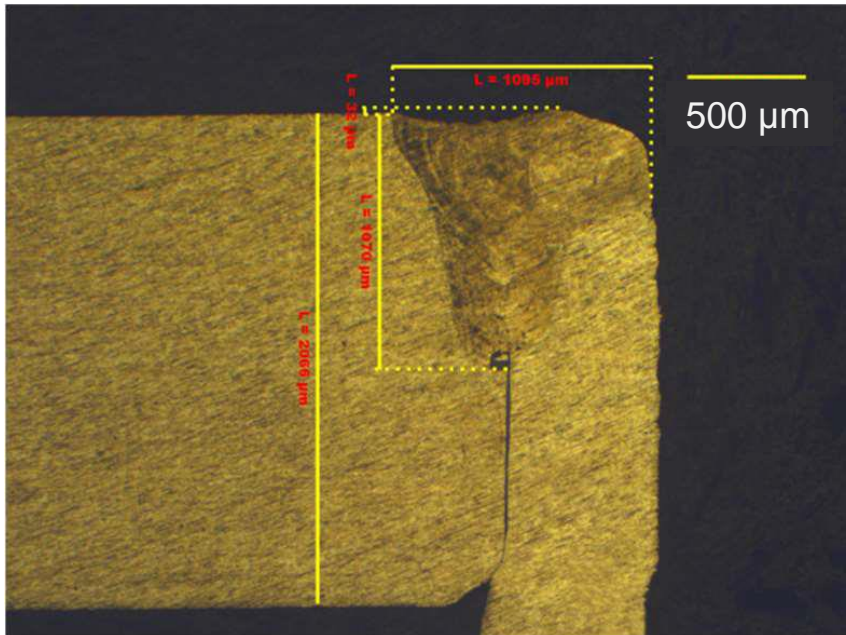
Parametri di prova:
Potenza = 1.5 kW
Velocità = 1.0 m/min



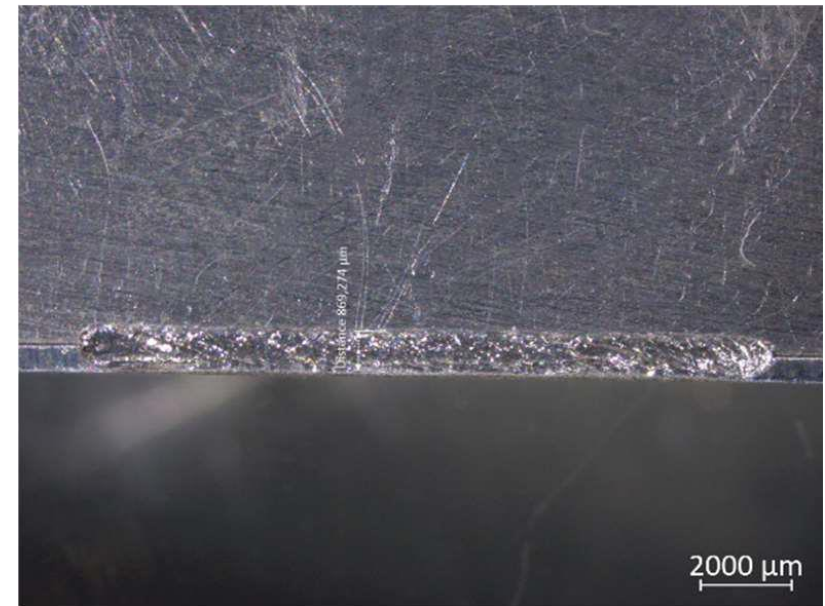
AISI 304



450W, 1 m/min



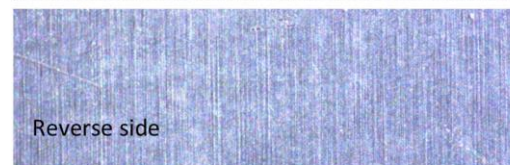
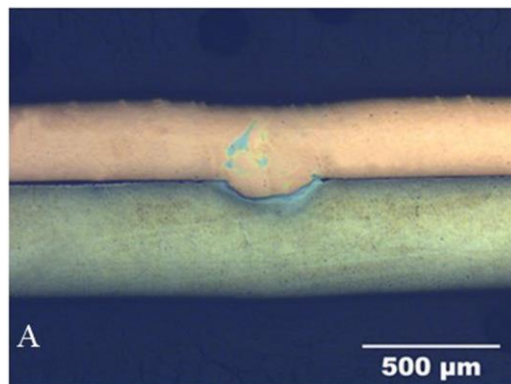
Al3003



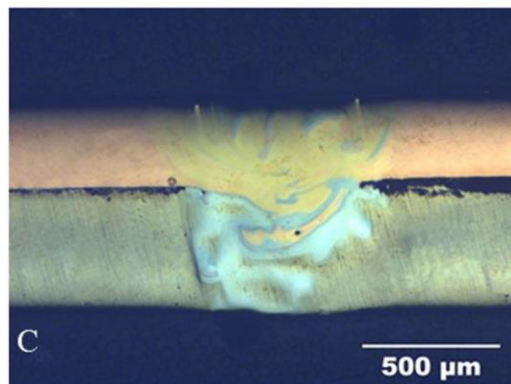
2000 W, 18 m/min

Esempi saldature

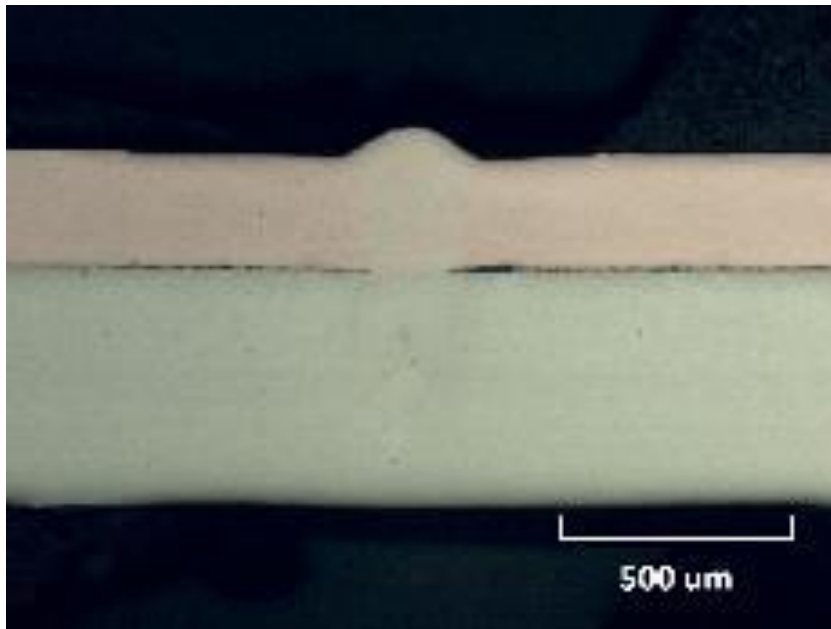
Al1050-Cu 99.5%



P=1300 W, v=120 mm/s

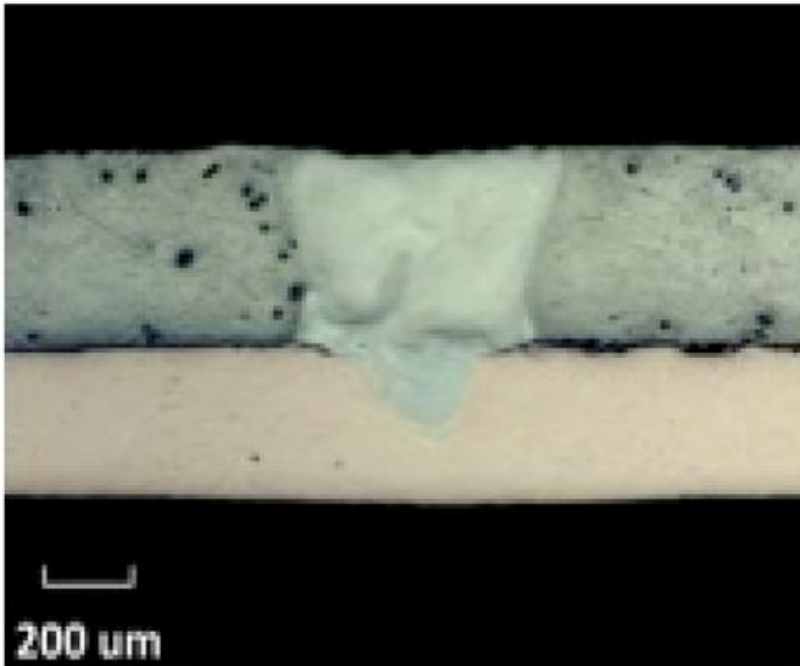


P=1500 W, v=100 mm/s



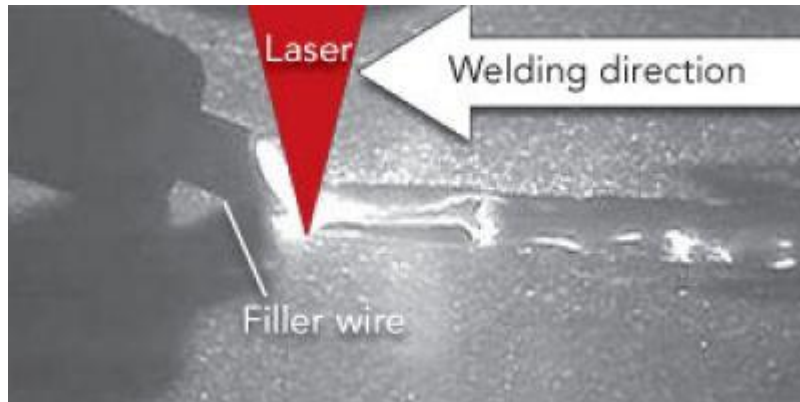
800 W, 18 m/min

Al1050-AISI304

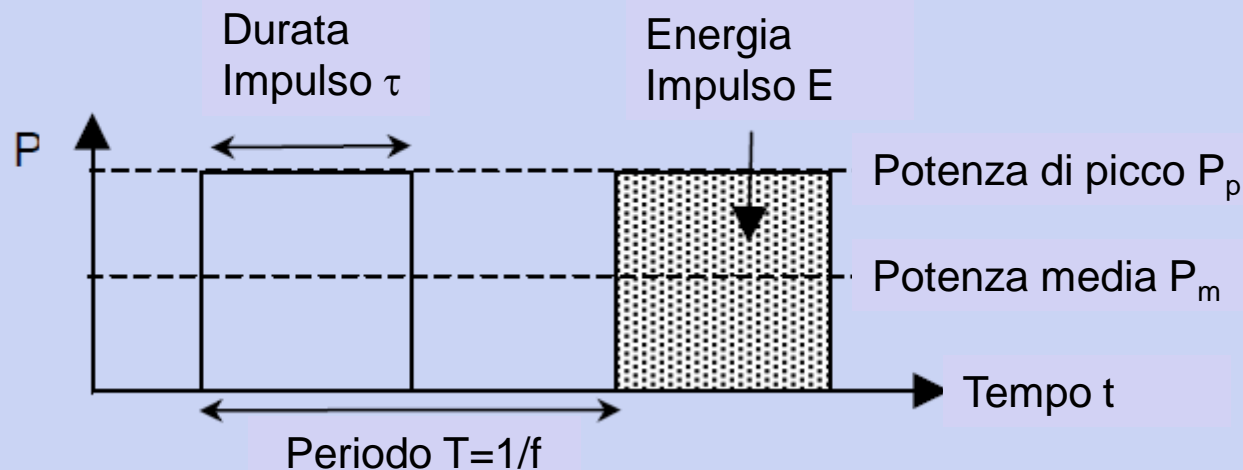


500 W, 10 m/min

Al1050-Cu 99.5%



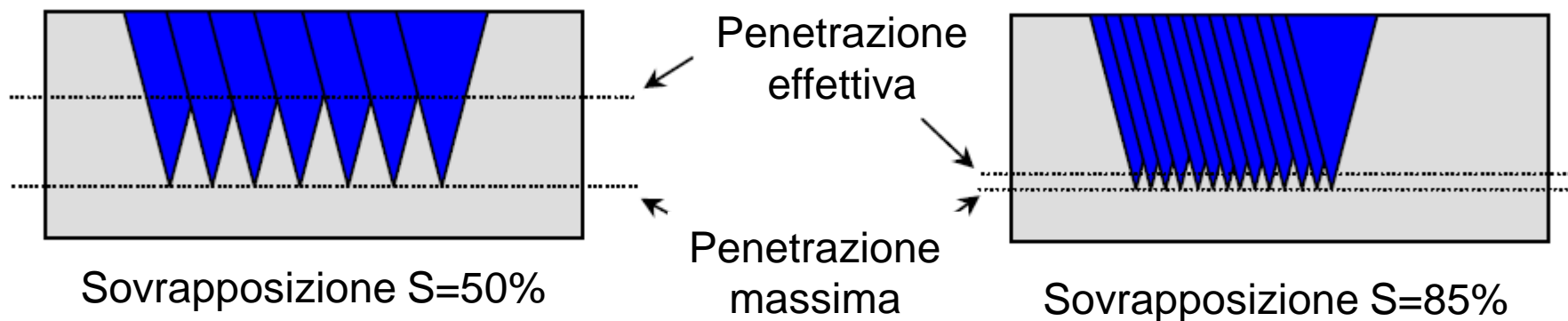
- Possibilità di saldare lembi con spessori differenti.
- Possibilità di colmare disallineamenti e cianfrinature.
- Possibilità di modificare la metallurgia del cordone.
- Possibilità di utilizzare sia il filo freddo che caldo.



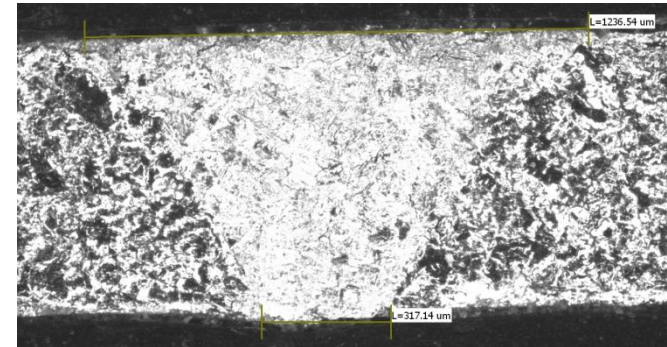
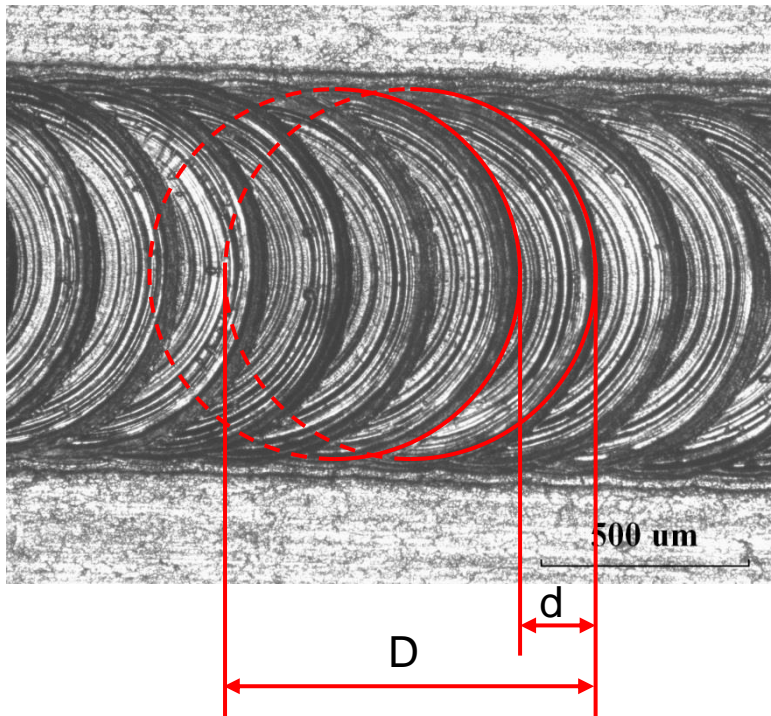
$$P_m = \frac{E}{T} = Ef$$

$$P_p = \frac{E}{\tau}$$

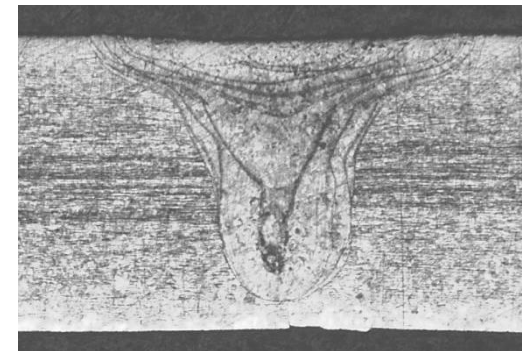
$$v = \left(1 - \frac{S}{100}\right) Df$$



Saldatura impulsata - 1

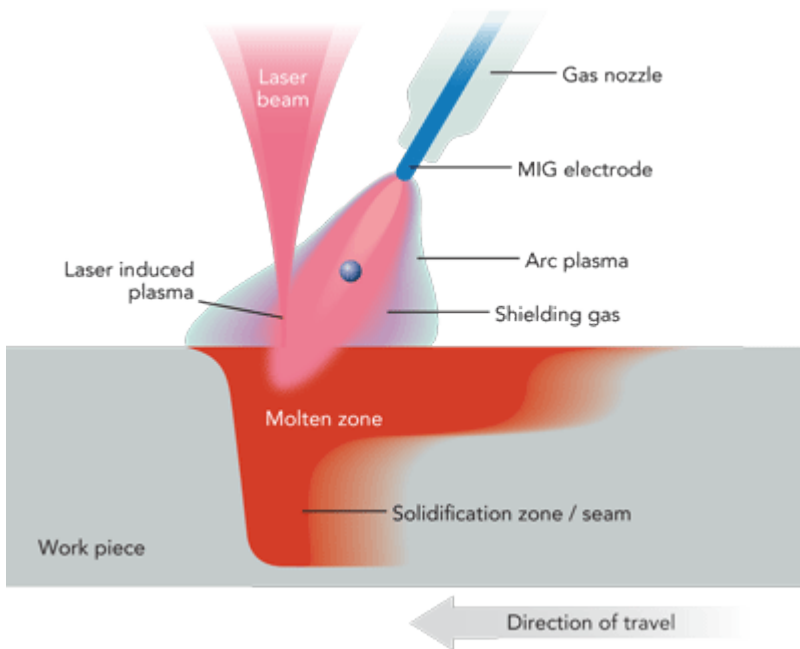


Titanio grado 1, spessore 0.6 mm



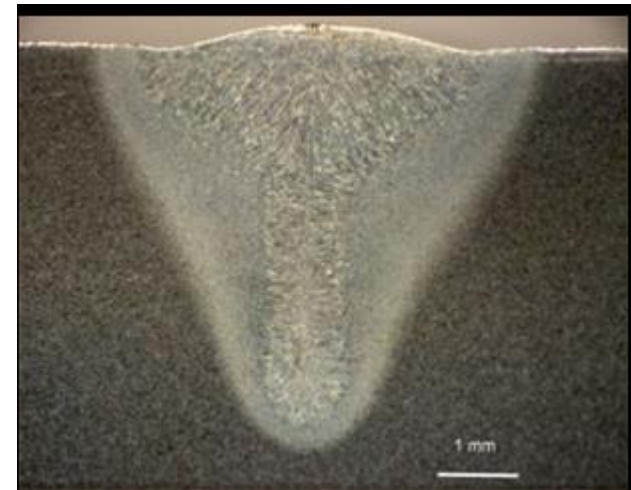
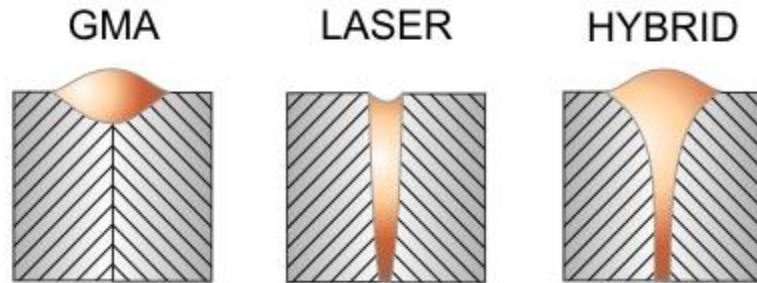
Acciaio inox AISI304, spessore 0.7 mm

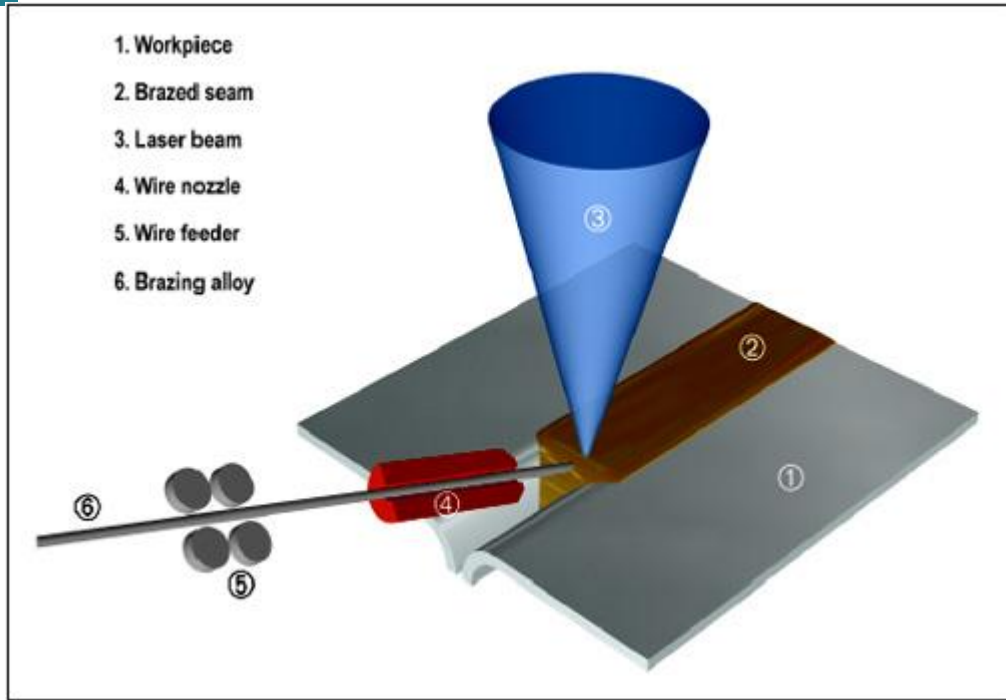
Saldatura ibrida LASER+arco



- Tutti i vantaggi relativi alla presenza del filo
- Ottimo compromesso tra penetrazione e capacità di riempimento.
- Il processo è sinergico: i pregi delle tecnologie coinvolte sono complementari

Saldatura ibrida LASER+arco – 1





- Variando potenza e dimensione dello spot si può ottimizzare la cessione di energia per le applicazioni più diversificate
- Possibilità di saldare lamiere zincate e materiali difficili
- Rendimenti di processo elevati e riscaldamenti molto localizzati



Light**WELD** 1500

Laser Welding System

**Smallest and lightest
laser welding system**



Light**WELD**

Riassumendo: pro e contro del LASER in saldatura

PRO:

- Elevate penetrazioni, elevata velocità di saldatura.
- Zone termicamente alterate ridotte, distorsioni ridotte.
- Possibilità di calibrare la cessione energetica per le più svariate esigenze.
- Combinando tecnologie diverse (filo freddo, filo caldo, processi ibridi, ...) si possono ottenere applicazioni specifiche per le più moderne richieste industriali.

CONTRO:

- Costi di impianto spesso elevati.
- Necessità di personale opportunamente formato.
- L'elevata densità di energia porta a modalità di saldatura radicalmente diverse da quelle tradizionali (necessità di nuove normative, ridefinizione delle difettologie, etc.).

Grazie per l'attenzione



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